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Should We Do Without Nuclear Power for Fear of an Accident?

Nuclear accidents often appear to the public as equally probable in all reactors, whatever the model, the host country, or the operator. Only the term "nuclear" seems to be retained, with no other consideration. In other words, it's as though nuclear accidents were a fatality. However, fortunately this view does not reflect reality: nuclear reactor accidents are deeply dependent on the regulatory context of the country in which they are installed, on their design, construction, operation, control, etc., and more globally on human behavior at all stages of their implementation.

Indeed, the root causes of major nuclear accidents are always due to human factors, for a simple reason: nuclear power plants are designed, manufactured, built, tested by their designers and constructors before commissioning. They are then operated, monitored, maintained, improved throughout their time of service by their operator. Finally, they are controlled at all the preceding stages by safety authorities. If an accident does occur, it is because several human failures have affected the above-mentioned chain of procedures and their consequences could not be prevented in time and contained. This holds even if the accident is due to an external aggression, for example an earthquake or a tsunami. These are just initiating events: if the accident occurs, it is because the parameters of such aggressions were poorly studied or poorly evaluated and/or the countermeasures implemented were poorly conceived or poorly calculated or were insufficient. Thus, human factors are always at the origin of an accident.

Three major accidents have occurred in the world to date: Three Mile Island (TMI for short) in the United States in 1979, Chernobyl in Ukraine in 1986, and Fukushima-Daiichi in Japan in 2011. None of them is due to fate, each has perfectly identified deep human causes.

Below, we analyze them from this perspective with, for each, the lessons drawn for the French nuclear fleet. Beforehand, a few basic nuclear safety principles are briefly reviewed for better comprehension.

Principles and objectives of nuclear safety

"Defense-in-Depth". This is one of the fundamental principles aimed at preventing a nuclear accident, or at limiting its consequences were it to occur. The principle is to interpose multiple successive lines of defense: first, preventive measures, whose purpose is to prevent an abnormal situation from evolving into an incident, then into an accident; secondly, palliative measures, to limit the severity and the consequences of an accident if it could not be avoided. In concrete terms, this may involve doubling, tripling or even quadrupling certain essential circuits in order to have the possibility to resort to several resources in the event of a failure; diversifying these resources technologically in order to avoid common origin failures; providing for material resources, procedures, and human actions to prevent and reduce the consequences of an accident, etc. A serious nuclear accident occurs only if ALL the prevention lines have been successively breached, and its most serious consequences only appear if the protection or mitigation lines have been breached in turn. These two cumulative conditions strongly reduce the probability of serious external consequences (a simple image to explain this principle of defense in depth is that of the holes in Swiss cheese: it is enough that only one hole is not aligned with the others to prevent a degradation from progressing towards a serious accident with serious external consequences).

<u>* The four objectives of nuclear safety.</u> They are summarized below:

1) Control the nuclear chain reaction

This reaction, which releases the usable thermal power of the reactor, must be controlled at all times. Two main elements are used to limit it:

- Reactor core design: it must be **self-stable**, i.e. it must naturally lead to the "smothering" of the chain reaction if the power increases inadvertently,

- **Automatic** control rod insertion in the core: the control rods must be ready for rapid insertion (within about one second) at all times, to promptly "smother" the chain reaction as soon as it exceeds a safety threshold.

Note: **Pressurized water** reactors (PWR) like those in France or **boiling water** reactors (BWR) like those at Fukushima are **self-stable** by design. This is not the case for Russian **RBMK** reactors, which are unstable in some operational regimes. This was **one of the major factors** in the Chernobyl accident (see below).

2) Evacuate the residual power generated by the nuclear fuel

This residual power is due to the natural decay of the radioactive fission products that gradually form in the nuclear fuel. It persists for a very long time **after** the chain reaction has stopped and heats the reactor core, which must therefore be cooled. This requires the short, medium and long term availability of safe cooling: **guaranteed water reserves** and reliable **electricity sources of last resort** to operate the motor pumps that inject the water into the reactor.

Note: Whereas the **control of core reactivity** requires highly sophisticated theories and technologies, the injection of water into the core of a reactor involves simple technologies, drawn from standard industry. The only difference is that they must be redundant and extremely reliable.

3) Contain the radioactive materials so that they do not spill into the environment

This containment involves three successive physical "barriers": the leakproof metal cladding of the nuclear fuel, the reactor vessel and its associated circuit ("primary circuit") and finally the leakproof containment building capable of withstanding a large internal pressure, i.e., 5 to 6 times the atmospheric pressure. Only if all three barriers fail in succession can radioactive material be released to the environment.

Note: **Pressurized water** or **boiling water** reactors have the three barriers, but not **RBMK** reactors, which have no containment building.

4) Control incidental, accidental and post-accidental critical situations

The final strong “link” in the defense-in-depth chain is to **set-up** both **material** and **organizational** provisions: crisis cells, internal and external emergency plans, and the possibility to call on the FARN (*force d'action rapide du nucléaire* i.e., rapid nuclear action force, the "nuclear firemen", see below). With this, the country's best nuclear skills, both theoretical and operational, capable of implementing palliative and/or curative actions in case of a serious incident or accident can be mobilized within a very short time. Some 300 experts, including the EDF local operators and central experts, and experts of the reactor designer (Framatome), of the IRSN and of the ASN[1], can be mobilized very rapidly in the event of a crisis situation, both locally on site and via videoconference with secure connections.

The TMI accident on March 28, 1979 in the United-States

* **Origin and consequences of the accident.** It occurred in a pressurized water reactor (PWR), the same type as those currently operated in France but constructed by a different builder. The 900 MW electrical capacity reactor in which the accident occurred had been commissioned in 1974, only 5 years earlier. It was thus very recent.

The accident, of human origin, is due to the defective configuration of a circuit after a test procedure, a situation that could have been handled if it had been correctly identified by the operators. The reactor had stopped automatically (chain reaction shutdown) and the residual heat had to be evacuated. However, due to insufficient information, because the data were not relayed to the control room, the operators did not understand the situation and stopped the automatic injection of cooling water into the reactor, the opposite of what should have been done. This led to a progressive heating of the reactor core until it partially melted (about 45%), of which about 20% sank to the bottom of the vessel **without, however, breaking through the 20 cm thick stee**l: **the bottom of the vessel was not punctured.**

The first barrier (fuel cladding) failed, the second (leakproof primary circuit) partially failed but not the bottom of the reactor vessel so that the third barrier constituted by the containment building fully played its role. The leakage to the environment was negligible.

* **The lessons drawn.** These were of primary importance for the worldwide nuclear community. The damaged reactor had been properly designed except for one item: its "man-machine" interfaces did not give sufficient information to the operators. This refers to the information that the operators have at hand to ascertain the exact state of the reactor along with the means of action that allow them to interact with the installation. The crucial importance of these interfaces was demonstrated: they help avoid or at least considerably reduce the risks of human error.

In France, this has resulted in a complete overhaul of these aspects, notably concerning: the addition of sensors to provide a more in-depth knowledge of the state of the core; the reorganization of the control rooms in order to group together in a more synthetic and didactic way the essential information on the state of the reactor; the overhaul of the operating procedures on the basis of a new approach, called the "reactor state approach", taking into account the physical parameters of the reactor that determine its real state, and no longer the sequence of events that led to the

1 **IRSN** Isntitut de Radioprotection et de Sûreté Nucléaire – The French national public expert in nuclear and radiological risks. **ASN** Autorité de Sûreté Nucléaire – The French equivalent of the Nuclear Regulatory Commission in the US.

degraded situation; extending the range of the operating procedures to new incidental and accidental situations; etc.

In-depth studies of what are known as "organizational and human factors" complemented this overhaul. These led to taking human error into account so as to reduce the **risk of individual error** through **training**, for example by systematically training operators on simulators, so as to familiarize them with the handling of incidental and accidental sequences, as was already practiced for aircraft pilot training. The **risk of collective errors** was reduced through good team organization, in particular by creating an **independent safety position**, with a safety engineer permanently on-site, to provide an independent view of the facility's operating safety and a diagnosis unrelated to that of the operators in the event of an abnormal situation, with direct access to the company's hierarchy. Finally, a "safety culture", which consists in focusing constantly on nuclear safety as a priority, began to be developed following this accident.

These organization and behavior issues continue to receive constant attention and constant improvements as they are essential factors for operational safety.

Finally, this accident led to the implementation of two major physical improvements in terms of defense-in-depth:

- The zirconium in the fuel cladding, when heated to a very high temperature in the event of cooling loss decomposes water into its oxygen and hydrogen components. Hydrogen gas is potentially explosive at certain concentrations. It must thus not be allowed to accumulate in the containment building. Passive autocatalytic hydrogen recombiners (i.e., that do not need electricity to operate) have been installed in the containment buildings of all the French nuclear power plants to recombine this hydrogen into water as it is produced in the event of an accident. Each containment building is equipped with several dozens of these recombiners.

Note: the explosions that occurred on the Fukushima reactors were precisely hydrogen explosions. These reactors were not equipped with recombiners.

- Since a severe accident with a core meltdown could cause the pressure in the containment building to rise above its design pressure, a filtering decompression system that retains 99.9% of the radioactive aerosols has also been added to guarantee the integrity of the containment buildings.

The Chernobyl accident on April 26, 1986 in Ukraine

*** Origin and consequences of the accident**. This accident occurred in a Russian RBMK reactor, which is very different from our water reactors. The origin of this type of reactor dates back to the 1970s. Its characteristics are that it can be built with fairly simple industrial means, that it can reach high power levels (1,000 to 1,500 MW), that it uses uranium that is only slightly enriched (2%), and that it is easily plutonium-producing. But it suffers from serious safety defects that were the cause of the Chernobyl accident, on a 1,000 MW-electric reactor that had been commissionned only three years earlier.

The root causes of this accident are twofold:

- RBMK reactors are by design unstable at certain regimes (especially low power regimes), i.e., they can spontaneously enter a runaway situation. In addition, the insertion time of the control rods that are supposed to stop this runaway condition was much too long. Plus, their design was such that at the early stages of their insertion, they would cause the power to increase instead of decreasing!

- A test totally out of line with the operating procedures was undertaken. It was carried out in violation of the safety instructions, the situation being worsened by the deactivation of the automatic safety protections, a maneuver that is obviously strictly forbidden. This aberrant behavior on the part of an operator seems to be due to forceful political pressure and personal threats to carry out this test at all costs. Several other RBMK reactor operators had previously refused to carry out the procedure because they rightly considered it to be much too risky.

To complement the analysis of the root causes of the accident, it is interesting to note that the Kurchatov Institute, attached to the USSR Academy of Sciences, declared several years later:

"[...] for a long time the USSR Ministry of Power had been operating plants with RBMK reactors [...] ***but did not take sufficient notice of the repeated unusual signals of the emergency power protection system [...] and did not demand thorough investigations of emergency situations. [...] We are bound to conclude that an accident such as that at Chernobyl was inevitable."***

This failure to take sufficient notice of repeated unusual signals reveals the lack of "safety culture".

What was bound to happen happened on April 26, 1986: the reactor became runaway and reached a power level that was estimated by experts to be between 100 and 300 times its nominal power! The damage was major: explosion of the reactor structures, followed by a general blaze of the graphite contained in this type of reactor. This resulted in massive radioactivity releases, both **locally** and at **high altitude**, the latter being dispersed at **large distances**. This was by far the most serious of all nuclear accidents to date.

Regarding the consequences of the accident on human lives, a 2008 report by UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation, an organization whose neutrality cannot be questioned) officially counted 62 fatalities within 22 years after the accident, including 47 firefighters who had intervened in the first few hours and were severely irradiated (28 died in the days and weeks that followed and 19 between 1986 and 2004) and, in the surrounding populations, 15 deaths from thyroid cancers, which occurred between 1991 and 2005.

<u>* The lessons drawn</u>. The lessons learned from the Chernobyl accident were limited in the **technological** field, as the technology of this reactor was very different from the PWR reactors used in France. Nevertheless, this accident drew attention to potential reactivity accidents that were revisited.

On the other hand, it led to several organizational advances: a major reinforcement of the "safety culture", whose absence had been glaring in the causes of this accident (unusual and repeated signals ignored); a strengthening of the **accidental and post-accidental crisis organizations** that existed since the TMI accident but were improved, particularly in terms of population confinement or evacuation; the **creation of WANO**, an association of world nuclear operators who decided to cooperate and share best practices to improve reactor safety and reduce the probability of new accidents; and finally, the creation of **INES** (International Nuclear Event Scale) intended to better inform the public on the seriousness of a nuclear incident or accident liable to occur in the world. The Chernobyl accident was classified at the highest severity level 7 ("major accident") as was the

Fukushima accident later. The TMI accident was retroactively classified at severity level 5 ("accident involving off-site hazards").

The Fukushima accident on March 11, 2011 in Japan

*** Origin and consequences of the accident**. This accident occurred on the east coast of Japan (facing the Pacific Ocean), on the site of the Fukushima-Daiichi power plant and affected four boiling water reactors - also different from the reactors used in France – that were commissionned between 1971 and 1978 with unit powers ranging from 440 to 760 MW-electric.

The initiating event was an earthquake of magnitude 9.1 on the Richter scale (a very high value) whose epicenter was about 130 km off the coast of Japan, which generated a very powerful tsunami. The earthquake, as intended, caused the automatic shutdown of nuclear reactors 1 to 3 which were then in operation. Because the external power lines were damaged by the earthquake, the diesel-powered emergency generators, which are designed to supply power to the emergency systems under these circumstances, took over immediately, as planned, to cool the reactor cores. But the more than 14 m high tsunami wave that arrived less than an hour later completely submerged and drowned the site, which was protected by a dike only about 6 m high. The emergency diesels were then irretrievably lost, as well as the cooling water reserves. The reactors were left without cooling and the temperature of their fuel gradually increased up to the partial melting of the cores of reactors 1 to 3 and the production of large amounts of hydrogen which accumulated in the reactor buildings and caused explosions and the release of radioactive elements into the atmosphere. However, there were no significant high-altitude releases as at Chernobyl, and thanks to favorable weather conditions, the releases fell mainly locally and into the Pacific Ocean. Only a small part of the Japanese territory was affected and other countries were totally spared.

Regarding the consequences on humans, the workers received limited radioactivity doses and the population were even less exposed thanks to the evacuation. Thus, the radioactivity caused no deaths in the short term and its long-term consequences were rapidly considered small by the WHO experts. This has been confirmed, with now 10 years of hindsight. The main trauma was in fact the evacuation for the approximately 130,000 persons concerned, which added to the trauma of approximately 18,000 persons caught in the tsunami and drowned.

*** Root causes of the accident.** Following this accident, two investigations were commissioned, one by the Government, the other by the Japanese Parliament. Their conclusions are edifying: excerpts from the report of the independent parliamentary inquiry commission were published in several French media in July 2012, in particular in the article titled "*Report of the independent commission on the Fukushima nuclear disaster: the truth unveiled*":

"The nuclear accident at the Fukushima Daiichi plant cannot be considered a natural disaster. It is a disaster of deep human origin that could and should have been foreseen and anticipated." And further on:

"The disaster is the result of collusion between the government, the regulatory agencies and the operator Tepco and of governance failures of these bodies"

Or again:

"All institutions have been deficient in their roles by proving incapable of implementing the most basic safety standards [...] Without this commission's investigation, most of the facts revealing the collusion between the regulatory authorities and the other actors would never have come to light. The regulatory body's independence from politicians, pro-nuclear ministries and the operators has been a travesty. They have effectively betrayed the nation's right to be shielded from nuclear accidents."

All is said, and very clearly by the Japanese themselves, confirming that the Fukushima accident is due to a **general and massive failure of the nuclear safety management** in Japan, extending from the operator to the safety authorities, implying the highest-level managers.

One of the key aspects that explains these conclusions is the voluntary dismissal of the tsunami risks by the decision makers, who knew for sure but turned a blind eye. According to the Japanese press, there had been a number of serious alerts, the most recent one in a publication by... the **engineers in charge of safety** at the Fukushima-Daiichi nuclear power plant themselves, who presented a communication at an international conference on nuclear engineering in Miami in July 2007.

Indeed, in its conclusion the communication said that the probability that a tsunami could exceed the maximum height of the site's protective dike (about 6 m), was estimated at 10% within the next fifty years... A probability of 0.1/50, or 0.002 per year, is considered extraordinarily high in the field of nuclear safety. Moreover, such a result was not surprising for this coastal region of Japan: the recent history of the country reports exceptional tsunamis observed in the city of Ōfunato, located 260 km north of the damaged plant: 25 m high during the 1896 earthquake and 29 m during the 1933 earthquake! That is a frequency of 2 exceptional waves observed within a little more than a hundred years before the one in 2011...

In view of such a result, there was only one option: to have it verified by independent studies and then, above all, to draw all the relevant consequences. But the Tepco management did nothing... And the Japanese safety authorities apparently head no objection...

This is probably, along with other elements, what allowed the Parliamentary Independent Investigation Commission to state that this accident was deeply human in origin, was foreseeable and could and should have been anticipated, and hence avoided.

*** The lessons drawn.** This accident, a catastrophe for the 130,000 inhabitants who had to leave their homes and their activities, a disaster for the image of nuclear energy in Japan and in the rest of the world (even if it is above all the "folly of men" that must be incriminated, as discussed above), had at least one virtue: it led the world nuclear community to look further into additional failure scenarios, allowing a further reduction of the probability of serious accidents, by reinforcing the existing protections.

France is one of the countries that have advanced the furthest in analyzing and implementing additional measures to deal with what was missing at Fukushima: the means of evacuating the residual power of the fuel elements, both in the reactors and in the deactivation pools for spent fuel elements. That is, ultimate electricity and water sources available even in the event of the most severe accidents due to external causes.

In France, three categories of complementary measures were decided very promptly after the Fukushima accident, and were implemented in the following order:

*** The establishment of a complementary organization for ultimate assistance.** This involves the creation of the FARN (*force d'action rapide du nucléaire* i.e., rapid nuclear action force) mentioned above, a sort of "nuclear fire department" capable of deploying in less than 24 hours to any nuclear site in France having suffered an accident, to deliver and implement autonomous means of re-supplying water and electricity, and to provide support to the operating teams. This structure, comprising 300 specially trained personnel, is based at four power plant sites to reduce travel time to the other sites. Each FARN team is equipped with all-terrain vehicles, capable of navigating roads in poor condition, as well as with emergency equipment (generators, pumps, etc.) that can be dispatched in less than 12 hours and in operation within 24 hours. In case of inaccessibility by road, the FARN can also use helicopters. This organization is operational since late 2015.

*** "Strengthening" of existing facilities.** This includes, in particular, the creation of **"strongly resilient facilities"** capable of supplying electricity and water along with control-command systems, even in the event of external aggressions (earthquakes, floods, etc.) that are much more severe than those taken into account in the initial or the revised regulations for these facilities. The following are examples (non-exhaustive):

- For each reactor, the addition of a "toughened" emergency diesel generator, capable of withstanding more violent earthquakes, site flooding, extreme winds, etc. These diesel generators come as an **addition** to the existing emergency diesel generators: 9 on a four-reactor site, 5 on a two-reactor site, and 4 on a site with a single reactor (EPR). The other addition is the creation of an ultimate secure emergency water supply outlet (i.e., one that cannot fail: e.g., groundwater, very large capacity water reserve). These ultimate capabilities are currently operational on all the sites; some sites are temporarily equipped with provisional water reserves (tarps with 1,000 m^3 fire-fighting water for each reactor) while awaiting certification of the definitive sources.

- For each site, the addition of a new building, the "Local Crisis Center" capable of withstanding the same increased aggressions, to serve as an advanced crisis management command post, including for long durations if need be.

*** In the longer term, implementation of additional measures to approach the safety requirements of generation 3 reactors** (those currently being built) **with the aim of excluding any radioactive release into the environment in the event of an accident.**

These improvements involve two major aspects: the first concerns **reinforcing the radioactive material confinement within the reactor building**, even in the event of a severe accident with core meltdown, thanks to the addition of a mechanism to spread out and cool the "corium" (products of the molten core) and additional means to evacuate the heat it releases in the containment building; the second consists in **reinforcing and diversifying the water supply to the spent fuel deactivation pools**, in order to secure their water supply in all circumstances.

These much more extensive improvements are currently being implemented on the 900 MW reactors and will continue to be on the 1,300 and 1,450 MW reactors.

To conclude

The analysis of these accidents shows that they were all brought about by humans: **simple human errors** in the case of TMI, **irresponsible major failings** on the part of decision-makers in the cases of Chernobyl and Fukushima, which are by far the most serious accidents. What lessons can be drawn from this?

First, that the concern for nuclear safety must imperatively start at the highest level of the chain of responsibilities, i.e. at the head of the companies that operate this energy. This was not the case for Chernobyl, whose safety weaknesses were neglected and where the operators were subjected to external political pressure during the test that led to the disaster, nor for Fukushima, where the managers turned a blind eye to the multiple warnings they had, with the tacit approval of their nuclear safety authorities.

The upshot is that this energy must be entrusted to managers who have the scientific and technical knowledge to appreciate the risks and to share these risks with their employees. This is the first condition: the safety message must start from the top and be diffused and shared at all levels of the organization, whose members must all have the necessary technical expertise and skills.

A second condition is to set up a controller-controlled relationship between a safety authority and an operator, a relationship based on competence and rigor on both sides. It is necessary to be subjected to an independent control authority that practices intelligent questioning to maintain a high level of vigilance and make progress.

With these two conditions it will still be impossible to state that an accident can never happen. Yet, they can make it extremely unlikely and, above all, reduce the external consequences if it were to happen, through well-designed preventive safety measures and protections.

France fits into this pattern: it has demanding regulations, a demanding safety authority, a qualified operator (the first party in charge of safety, do not forget) who places safety at the very top of its agenda, and a policy of safety improvement that is based, since 40 years, on feedback from operating experience, in France and abroad, i.e., on the complexity of reality, which is much greater than the sole imagination of men, which is necessarily limited: no one can claim to have "envisaged everything". France, along with a few other countries, has made extreme progress in improving the safety of its reactors, in response to the accidents that have occurred throughout the world. This without forgetting the importance of organizational and human factors that structure the "safety culture".

Finally, we must not neglect deeper cultural aspects. It is Europe that "invented" humanism, which places human life as the foremost value, and this has a profound influence on behavior. It is perhaps no coincidence that this continent, for a long time the most nuclearized in the world along with the United States, has not experienced a serious nuclear accident. On the other hand, neither the USSR nor Japan had a humanistic culture (this is changing in Japan with the emergence of new generations); they tended to put human life beneath many other considerations.

Another aspect of the value given to human life is highlighted by François Lévêque in his excellent book "*Nucléaire On/Off*". This is the fact that operators at all levels of responsibility in French nuclear power plants, from the top manager to the workers, including engineers and technicians, all live with their families in the vicinity of the plants, within a radius of 10 to 20 km. They are members of the local population, many of them originate from the area. Consequently, beyond their moral responsibility towards these populations and more generally towards the country, they have a major interest in not placing their own families in danger.

In conclusion, provided that it continues to be operated in a responsible and rigorous manner, nuclear energy does not constitute, by far, the greatest danger to human life: in the half-century that it has been in use in France, this energy has not caused a single death from radiation or contamination. During that time, more than 500,000 persons have died in road accidents. This factual observation should be reassuring to honest citizens at a time when humanity is faced with the immense challenge of climate change, which carries many dangers, including for human lives.

Nuclear power is, along with hydroelectricity, the lowest CO_2 emitter of all electricity sources; it is dispatchable (capable of adapting to demand); it can be produced in very large amounts; it provides a high degree of energy independence (the uranium stocks on French territory are sufficient for several years' production); and finally, it is cost competitive, guaranteeing a reasonable long-term price for consumers.

Can we afford the luxury of doing without this source of energy when we have the human, scientific and technological capacities to handle it, and when the other available low-carbon sources are limited to wind power and photovoltaic panels, the only options with significant development potential but are intermittent and extremely variable? In any case, they would be unable to produce all the electricity needed in 2050, as the results of the latest RTE study clearly show.

The consequence is major: the choice of nuclear power is not merely a technological choice, it is a societal choice: to do without it would lead to agreeing to consume much less energy in 2050, because electricity will be its main component. Moreover, this reduced quantity of electricity would be very expensive, with deleterious repercussions on our status as a developed country and the standard of living of its citizens. The certain refusal on the part of the citizens of this severe degrowth would lead to massive fossil gas imports, whose CO_2 emissions would have to be captured and stored, at great cost. Last but not least, it would place us under the geopolitical dependence of the gas suppliers.

Is this really the future we want? It must be placed in perspective with the extremely low residual risk of a nuclear accident.

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Sources and References

The three nuclear accidents that have occurred worldwide have led to a very large number of analyses and publications that cannot be fully listed here. The present study is based on a number of these, including:

* Regarding the accidents themselves, texts published by international and national organizations bearing on:

* Analyses of the causes of these accidents and their development (IAEA: International Energy Agency; NEA: Nuclear Energy Agency; ASN: Nuclear Safety Authority; IRSN: Institute for Radiation Protection and Nuclear Safety; SFEN: French Nuclear Energy Society);

* Analyses of their impact on the environment and health (WHO: World Health Organization; UNSCEAR: United Nations Scientific Committee on the Effects of Atomic Radiation; IRSN);

* Concerning the Organizational and Human Factors in risk management as well as “safety culture”, numerous texts have also been published, in particular by the IAEA; the NEA; the IRSN;

* The article: “*La disqualification de l’expertise : un risque grave pour la rationalité des décisions politiques*” (The disqualification of expertise: a serious risk for the rationality of political decisions), Yves Brechet, November 28, 2011, Académie des Sciences morales et politiques. Mr Brechet is a member of the French Academy of Sciences and of the French Academy of Moral and Political Sciences;

* The Opinion of the Academy of Sciences on the French nuclear industry - January 10, 2012;

* Regarding the Fukushima accident, the article titled: “*Rapport de la commission indépendante sur la catastrophe nucléaire de Fukushima : la vérité dévoilée*” (Report of the independent commission on the Fukushima nuclear disaster: the truth revealed), Jean-Marc ROYER, July 23, 2012; http://www.fukushima-blog.com/article-rapport-de-la-commission-independante-sur-la-catastrophe-nucleaire-de-fukushima-la-verite-devoilee-108417997.html

* The book: “*Nucléaire On/Off*”, By François Lévêque, Dunod, November 2013;

* Regarding the latest post-Fukushima modifications to French reactors: “Position de l’ASN sur les conditions de la poursuite de fonctionnement des réacteurs nucléaires de 900 MWe au-delà de leur 4è réexamen périodique” (ASN's position on the conditions for continued operation of 900 MWe nuclear reactors beyond their 4th periodic review), asn.fr, December 2020;

* Finally, this paper has been carefully proofread by former French nuclear power plants managers and includes their informed remarks.