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Views & Comments

The Future of Nuclear Energy Relies on Integrated Reactor Development Processes

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Being a nuclear operator is a responsibility like no other. As a power generation company, Électricité de France (EDF) has the important mission to deliver electricity to the population in order to meet its daily needs in a timely manner. On top of this public service mission, as a nuclear operator, we have the hefty responsibility of ensuring the safety of our facilities. It is crucial to maintain the trust of the stakeholders, and above all that of public opinion. Although the same motto is relevant for a broad range of industrial sectors—aircraft, automotive, and construction—I believe it to be even more crucial for nuclear. Indeed, safety is the key in ensuring the development of the nuclear industry in the world today.

1. Operation is key in nuclear safety

How can safety be guaranteed in nuclear facilities? This question is paramount for the future of our industry. Looking back at the main accidents in the history of nuclear development—Three Mile Island, Chernobyl, and Fukushima—it is clear in each case that operation was at the root of the accident. The Fukushima accident sparked a global debate among nuclear industry companies, governments, and proponents of public opinion on the safety devices of the plant and their inaccuracy. Around the world, the concern for safety increased and equipment was upgraded. Nuclear reactor makers have pushed forward the "Generation III" label with a new level of safety equipment as a guarantee against further Fukushima-style accidents. When it comes to addressing safety issues, however, a focus on technology is misleading. In fact, the Fukushima accident was due to a weakness in the industrial organization and to mistakes during the operation process. It is, of course, necessary to have the highest level of "technical safety" for equipment at nuclear facilities in order to limit the consequences of severe accidents. However, these technological devices are of limited use unless they are properly integrated into a consistent operation culture. Technology cannot cover every situation, and especially not the numerous possibilities of human misconduct and error.

After Fukushima, it was apparent that the safety of nuclear facilities relies on their operators. This fact has been blurred in recent decades because reactor manufacturers have been eager to promote and upgrade their own technologies, on the premise that their newly developed technologies are safer than those used formerly and than those of their competitors. This global competition has led to an "over-technologization" of the nuclear industry. It has brought some interesting innovations; yet it has also spread the false idea that technology will be the ultimate solution for nuclear safety. Thus far, over-technologization has led to high additional costs and to complex checking processes, creating difficulties for companies in charge of construction. Technological innovation is very important and must be strongly supported; however, it cannot be the driver of the whole industry. Technology must be developed in accordance with the realities of operational needs, for the sake of safe and competitive operational records. For this reason, I believe that operators should be the main drivers of technological innovation and should draw the industry toward excellent safety levels.

2. Three pillars to master industrial tools

To achieve such high safety levels and operational performances, operators must master their production tools. To do so, they must focus on three specific areas of the nuclear industrial business: the design of the production tool, an extensive knowledge of the suppliers and equipment (constituting these production tools) and, most importantly, the broad in-depth empirical knowledge acquired through operating these tools. It is the interaction of these three areas that determines the quality of the industrial process as a whole and therefore the level of safety. Of these three pillars of the organizational system, empirical knowledge above all is the system's engine. Many industrial companies have built their success stories on feedback from empirical knowledge. A well-known case is that of Rolls Royce, famous for its luxury cars but also a major aircraft engine manufacturer, the second largest in the world. All of their engines are fitted with sensors that transmit data (oil, pressure, etc.) when the aircraft is flying. As a result, Rolls Royce has built up an in-depth knowledge of engine behavior during operation, enabling the company to continuously fix flaws and upgrade their performance.

Gaining full operational control through a complete knowledge of the industrial tools is the ambition of any responsible industrial actor. The French nuclear power industry is no exception. EDF has collected empirical data over decades of reactor operation and

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this data has now become a reference for industrial management. In order to tap into this large quantity of data and use it as a lever to master its industrial tools, EDF has set up an original integrated industrial model. This organization is consistent with the initial goal of covering the three components of our strategy: design, suppliers, and operational feedback. Since the very early days of nuclear power plant construction in France, during the early 1970s, EDF has put at the core of its activity a consistent team of engineers tasked with setting up a continuous improvement loop based on empirical data. Today, around 5000 engineers are assisting 20 000 operators. These workers are a key element in enabling EDF to benefit from its learning curve, challenge its habits and processes, and adapt and upgrade its management schemes; and all this with the constant goal of achieving excellence in both operations and safety standards.

3. Being an architect of the nuclear industry

In order for this integrated model to be consistent and efficient, its extent should not be limited to plant operation. Mastering the industrial tools requires extending the improvement loop to the design of the plant and to the manufacturing of the equipment used in operating it. This requirement has led EDF to build strong links between the company as an operator and its suppliers. There is constant dialogue between engineers and manufacturers on equipment standards, such as on valves, pumps, pipes, and so forth, as well as during each step of the plant design and construction process. The empirical feedback acquired through operation benefits the whole industry, and the whole industry aligns with the common goal of achieving the best performance and safety records.

The operator is at the core of this integrated industrial model and plays a very special role as both the engine and the driver of the whole system. This role is labeled "architect-engineer." From this central position, EDF has completely mastered its industrial production tools and has developed its own reactors. Our company is able to implement an articulated industrial policy: It determines how contracts are divided into batch lots, sets the rules for the competition policy, and monitors the certification of national or foreign suppliers. The architect-engineer can bridge the needs of the operator and the capacity of the manufacturers; it inspects the production line and monitors the details of the contractual requirements. The relationship between the architect-engineer and the equipment suppliers is a key part of industrial mastery. Such organization requires the operator to have a full knowledge of the industrial context.

4. Leveraging on standardization to improve safety and performance

The EDF industrial model is oriented toward safety and performance. It also steadily improves the efficiency of industrial facilities and thereby leads to a long-term lowering of construction costs for nuclear power plants. The model aligns with a standardization of the industrial tools. An integrated model and standardization are mutually promoting elements that push the industrial organization in the same direction. Indeed, standardization is another factor that increases the value of empirical feedbacks. As an operator develops industrial facilities based on the same industrial technology and standards, the scale of its improvement loop increases. For EDF, in France, the smallest flaw during the operation of one of our 58 reactors is analyzed by our engineers and the feedback is used to upgrade the performance of the other reactors, or to prevent the same problem from happening again. Standardization improves the efficiency of the learning curve; however, the cornerstone of the learning curve is the sharing of operation feedback, whether with a single operator or between different operators around the world, even if they do not use the same technology.

Standardization was a clear choice in the early stages of development of the French nuclear fleet. The development and records of the French fleet show that standardization has several advantages. In addition to increasing the amount of empirical data and therefore leading to a better mastering of the facilities, standardization produces a crucial "series effect." This effect is paramount to such a capital-intensive industry. Thanks to standardization, construction costs are lower, as are operational costs, which appear to be 40%–70% lower in France today than anywhere else in the world. To make full use of the virtuous circle of standardization, EDF has promoted the launch and development of a comprehensive technical reference base: the "codes and standards" for the nuclear industry. Piloted by the AFCEN[†] association, these codes are very rich technical frames of reference nurtured by our knowledge and experience. The first design and construction rules were established in the 1980s, followed by codes progressively covering every area of the nuclear industry: the chemical composition of materials, how these materials are fabricated, prerequisite regulatory tests for equipment going into service, welding, and so forth. These dense and structured texts were progressively enforced by safety authorities and equipment suppliers. Today, these codes and standards are the best tool for monitoring the accuracy of our industrial organization and the conformity of the facilities and equipment. They provide a very solid and concrete foundation for standardization and the implementation of an improvement loop within the nuclear industry.

The whole French nuclear industry is organized in such a way as to benefit from empirical feedback. This organization has excellent safety and performance records. France has experienced no nuclear incidents in its roughly 40-year nuclear operation history (no incident above level 2 of the International Nuclear Event Scale or INES chart), and the availability of the French fleet is very high, reaching 90% during the peak season in winter. Thanks to its architect-engineer position, EDF has been able to continuously upgrade the safety level of its nuclear facilities through regular comprehensive check-ups, enabling the company to implement improvements stemming from its empirical knowledge. In that respect, we can now say that the oldest nuclear plants are the ones with the highest level of safety.

5. Nuclear industry benefits from international cooperation

I believe that integrated organization is not only a model for EDF and France but should be extended to the whole nuclear industry world-wide. The countries with the most dynamic nuclear industries, namely France, Russia, and China, have already adopted this integrated model for their nuclear programs. Spreading the architect-engineer model benefits the performance and safety of the whole industry. From this perspective, we should enhance cooperation and exchange between operators around the world in order to share their experience feedbacks. To a certain extent, this has been the case between the French and Chinese nuclear industries since EDF and China General Nuclear Power Corporation (CGN) developed China's first jointly-built nuclear power plant in Daya Bay (Guangdong) 30 years ago. The integration of

[†] French Association for the rules governing the Design, Construction, and Operation Supervision of the Equipment Items for Electro Nuclear Boilers.

best practices and the transfer of empirical knowledge, acquired while running the French fleet, has spared China a decade of development. Today, the convergence of the French and Chinese reactor fleet standards and the long-term cooperation between EDF and its Chinese partners has broadened the basis for collecting experience feedback, with mutual benefit. As the next step in cooperation, EDF is inviting its partners, CGN and the China National Nuclear Corporation (CNNC), to cooperate in addressing third-country markets. This step will help Chinese players to avoid a long and costly learning curve when facing the requirements of foreign safety authorities, while EDF will benefit from the strong industrial capacities of Chinese nuclear players. Our EPR™ reactor project in the UK follows the same path. I believe this virtuous cooperation should be promoted even further and spread widely. EDF has achieved some progress by founding the World Association of Nuclear Operators (WANO), which aims at sharing operating experience and consequently enhancing nuclear safety for all the countries involved.

EDF has not waited for a global framework of data-sharing; it has already started to learn from others' experiences. Using the same improvement-loop approach that was applied within the French fleet, EDF has learned from the history of nuclear accidents. For example, after the Three Mile Island accident in 1979, several modifications were made on the French fleet, both technical (e.g., a hydrogen recombining device and sand-filters) and operational (a piloting scheme to operate the reactor in precarious situations). Similarly, after the Fukushima accident, 300 EDF engineers worked for six months to learn from it; they came up with a large range of improvements for the nuclear reactors in order to enhance their safety. This comprehensive upgrading program is still continuing in France, with significant investments planned in safety equipment and devices.

One must admit that the global nuclear industry is currently ruled more by competition than by cooperation. This trend is enhanced by the "turnkey" approach that is supported by reactor suppliers. According to this model, which has been adopted by the United States and Japan, the constructor leads the organization of the industrial project and is in constant communication with the safety agency and suppliers during the design and construction phase. Except for being the final paymaster, the operator has a very minor role in this crucial phase before the commissioning. However, the operator is solely responsible for safety during operation. The nuclear industry is not like its automotive counterpart: The nuclear operator must master its industrial tools to prevent any accident, whereas a driver need not have an in-depth knowledge of the internal functioning of his or her car in order to avoid crashes.

6. What our industry needs

The fact that the Fukushima accident occurred in a country with a very high level of technical skills and access to advanced technologies shows that the key point for safety is not technology but industrial organization. One of the weaknesses of Japanese operators, for instance, is their lack of exchange with manufacturers regarding operational experience. Consequently, the same defect in equipment can lead to the same accident twice because the lesson has not been learned. Another drawback may be territorial fragmentation: In Germany, for example, the local Länder (local governments) sets different nuclear safety standards and rules, which lead to one plant having different organizations than another. In such a situation, it is challenging if not impossible to share empirical knowledge. The turnkey approach of the nuclear industry has led to this kind of situation, with very serious consequences for safety. Beyond this approach, the whole technology-oriented framework sets up a deadlock for the nuclear industry. Fierce competition between vendors leads to the deceptive belief that having the most sophisticated technology is a guarantee of a facility's safety, and this belief overshadows the importance of operational practices. Following their commercial purposes, vendors tend to promote new models, leading to a fragmented industry landscape with a less efficient learning loop.

Taking a broader look at the nuclear industry enables us to identify additional players with key roles in ensuring safety. The organization of the sector, with the operator at its core as architect-engineer, is necessary but insufficient. To ensure a stable and balanced development of the nuclear industry and good safety levels, two other players have crucial roles: the state, which is in charge of defining the energy policy, and the safety agency, which is in charge of checking and enhancing the safety standards through dialogue with the operator and manufacturers. We all know from experience that a healthy development of the nuclear industry requires a long-term perspective. By setting up a long-term and well-defined framework, governments enable operators to play their roles as architect-engineers. This framework is, for example, composed of clear guidelines for the long-term evolution of the energy mix, of wisely oriented subsidies, and lastly, of a consistent schooling program to support the development of the industry. As discussed earlier, safety lies in the engineering capacity of the operator. This kind of skill requires years of training for a workforce to be operational and efficient. Moreover, safety is as much a question of culture as one of skill. Once in operation, operators still need years of training in order to utterly implement the engineering culture. In addition, investments in nuclear energy are huge and spread out over decades: 5–6 years for construction, 40–60 years of operation, and at least 20 more years for decommissioning—almost a century-long commitment! However, the electricity needs in every country are changing quickly and companies are exposed to financial pressure, commanding short-term returns on investment. In this respect, the time constraint is challenging for nuclear players and can have consequences for safety. The state has a role to play in helping nuclear industry players to tackle this challenge.

7. A few guidelines for the future of nuclear reactors

As China's nuclear industry has entered full-speed development, the question of timing is now very important in order to pave the way for a healthy capacity for growth alongside high safety levels. In France, where we have been focusing on operational experience feedback, our engineers are steadily working to improve our industrial tools, providing guidelines for the future of nuclear reactors. What are these guidelines as of today? We keep to our principles: We implement the learning curve from empirical knowledge, and we require the suppliers involved in the design of the facilities to better take into account their constraints. This integration process and the cooperation dynamics between nuclear players do not mean that there is no room for market-based rules. For example, whereas cooperation between nuclear operators is highly desirable, competition among equipment suppliers is a very good lever to stimulate innovation and thereby enhance the performance of the whole industry. In my opinion, this virtuous balance between cooperation and competition is embodied by China's thermal power market. On the one hand, Chinese generation companies develop almost the same industrial tools based on very similar technology. On the other hand, the strong competition between manufacturers has brought very competitive manufacturers to China, which are now winning contracts all over the world.

When discussing the future of the nuclear industry, we must also consider the needs of and requests from clients, and competition with other energies. In that respect, every industrial actor must find the best design to keep costs reasonable while maintaining safety standards at their highest level. Standardization could be a solution to lower these costs and, at the same time, enhance the improvement-loop efficiency. Today, even if we in France and Europe have no plans for in building nuclear reactors on a large scale, we must continue to leverage on standardization. How? The design of our plants should avoid specific equipment that is not already manufactured on an industrial scale. This choice enables us to save time and money when replacing these spare parts. For example, the mere decision of developing tailored taps for one type of nuclear facility (or even for one function within this facility) can trigger heavy logistical burdens and significant additional costs. We must balance the operational benefits of this decision. Nuclear equipment must be sourced from existing industrial productions when possible regarding nuclear specific standards. This is part of a general trend that aims at developing a design that matches the realities of industrial needs.

Like many other industries, the nuclear industry is implementing "design-to-cost" principles to avoid useless technical sophistication and its corresponding additional costs. The accumulation of safety recommendations and the extension of some specific equipment for special sites have led to a large number of details and devices in the design of our nuclear plants. Faced with this increasingly sophisticated design, we have to integrate regular self-check and balance processes: Our engineers must question design choices in order to get rid of unnecessary equipment. This questioning is also part of the improvement loop. Moreover, because engineering is the cornerstone of our industrial organization, we have to keep increasing its efficiency as well.

Taking these principles into account, we are able to guide the evolution of our nuclear plant design in the right direction with a general target of optimization. This strategy prepares for the future of nuclear plants, which will benefit from strong links between engineering and operation, monitored costs, and the best safety levels possible. Today, nuclear energy is the only steady and massive low-carbon energy. In that respect, the nuclear industry makes a unique contribution toward fighting climate change. Industrial players have the responsibility to deliver the right production tool to achieve this historic mission.