Constructing Competitiveness

*The Politics of Engineering Work in the French Nuclear Program, 1955–1969**

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Introduction

The term *technological competitiveness* invokes connections between technology and economics. But what precisely does it mean to say that one technology is "competitive" with another? Are judgments about competitiveness made on the basis of technical design? Of price? Do such judgments, along with the bases on which they are made, depend on political and economic agendas? In short, is this term immutable, as careless usage often implies? Or is it historically contingent, depending on the political, economic, and cultural climates surrounding the technology in question? Why and when do engineers, industry leaders, and politicians choose to label a particular technology "competitive"? What does such labeling imply for the development of that technology?

In this chapter, I examine French nuclear development from 1955 to 1969 to argue that we cannot assume that the term technological competitiveness has a fixed meaning. The notion of "competitiveness" acquired three different meanings over the course of these 15 years of French history. These meanings changed with the shifting political, economic, and cultural climates of French industrial development in general and the nuclear program in particular. Furthermore, each meaning was closely connected both to a distinctive kind of organization of technological work and to a particular vision of the role of nuclear technology in French economic and industrial development. The chapter begins with a brief discussion of the economic and political climate in France in the 1950s and 1960s. The body of the chapter is

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then divided into three parts in order to trace the shifting meanings of competitiveness in this time period. In the mid- to late 1950s, engineers in both the atomic energy commission (the Commissariat à l'Energie Atomique [CEA]) and the nationalized electric utility [Electricité de France (EDF)] used competitiveness to designate technological sophistication. Whether or not a reactor was competitive depended on its technical characteristics; in turn, how "advanced" these characteristics were provided a measure of institutional and national prestige. This use was accompanied by a form of engineering practice that was based on institutional traditions and that relied almost exclusively on trial and error. Between 1960 and 1964, competitiveness took on an economic dimension: the term referred to the cost of producing nuclear energy relative to that of producing conventional energy. This use of the term was paralleled by the introduction of various methods of formal economic analysis into engineering work. Engineers at EDF first used these analyses to defend their existing technological choices; subsequently, these methods became an integral part of their practice. In the mid- to late 1960s, competitiveness meant comparing the cost of the French gas–graphite reactor design with that of American light-water designs. This shift in meaning emerged from shifts in economic thinking within the government and ensuing debates between the CEA and EDF over issues of industrial policy and the organization of reactor contracting and construction.

Charles de Gaulle's return to power in 1958 brought drastic changes in the political and economic climate of France. Although the nation had undergone significant economic recovery during the Fourth Republic (1946–1958),[1] the frequent changes in political leadership had not encouraged confidence in government stability. In 1946, the postwar government had created the Commissariat Général au Plan (the Planning Commission), an independent state agency whose purpose was to draft multiyear plans intended to guide the recovery and development of the French economy. These plans represented the government's desire to follow an economic path between the free-market capitalism of the United States and the state-directed economy of the Soviet Union. Not intended to coerce industry into taking specific actions, these plans aimed rather at providing industrial leaders with suggestions for the production goals that would best enhance France's economic development. The First Plan had clearly stimulated reconstruction: in setting construction and production goals for all the major branches of industry, it gave company leaders sufficient confidence to make investments aimed at modernization. The Second and Third Plans, however, were less sector-oriented; furthermore, political turmoil delayed their approval by the government and their subsequent implementation. They were largely ignored by industrial leaders, who apparently did not see the point of paying attention to such plans when the government changed every few months.[2]

De Gaulle intended to disassociate himself and his government from the political turmoil of the Fourth Republic. In order to emphasize the changes he intended to make, he rapidly proposed a new constitution and proclaimed the advent of the Fifth Republic. The new republic removed certain powers from the hands of Parliament and placed them squarely in the executive branch of government. De Gaulle strongly believed in the importance of the nation-state, seeing it as the "crystallization of social bonds."[3] He wanted France to become a modern country—as he put it, to "marry her century." For him, this meant that the country's leadership had to be both stable and decisive. Incorporated in these views was a strong sense of *dirigisme*, the notion that the State should have a strong hand in directing the economy. Weary of political upheaval, the French felt only too glad to support him in his endeavor and expressed confidence in the stability of the new government.[4] In this new political climate, the concept of economic planning regained both popularity and respect among industrial leaders.[5]

De Gaulle's position on nuclear issues exemplified his political stance. The governments of the Fourth Republic had consented to a national nuclear program, but the true policymakers in nuclear issues throughout most of the 1950s were the engineers, scientists, and administrators who headed the CEA and EDF.[6] By the end of the Fourth Republic, Parliament had approved a French atomic bomb project, but de Gaulle's vision of French nuclear development had far greater scope. He planned to bestow upon France a full-fledged nuclear arsenal: the *force de frappe*. Further, unlike the heads of the nation's nuclear efforts in the mid-1950s, he had no intention of keeping his plans secret. This unequivocal stance on the military atom had a twofold implication for the civilian nuclear program. First, it inspired great confidence in the future of the gas–graphite design. Clearly, the government had no plans to halt the reactor program. Second, it gave the CEA greater leverage over EDF in demanding the military plutonium that the utility was capable, albeit unwillingly, of producing in its reactors. As long as de Gaulle was in power, EDF could not outright refuse to perform this service.

The CEA and EDF were both state agencies created shortly after World War II. The CEA's purpose was to conduct nuclear research and, eventually, provide France with a nuclear program. EDF's goal was to give the nation a reliable and abundant supply of electricity. In the mid-1950s the two institutions began collaborating on the development of gas–graphite reactors. While the CEA wanted to use these reactors to produce weapons-grade plutonium for its (still secret) military program, EDF wanted them to generate electricity. The first four reactor projects—three run by the CEA, one by EDF—were thus fraught with tensions between the two agencies. Both considered themselves the guardians of the interests of the French state, and made or justified technological decisions accordingly. This attitude intensified in the late 1950s and throughout the 1960s. Between 1955 and 1967, the two institutions collaborated in the design of five more gas–graphite reactors. In chronological order of design and construction, these were: EDF2 (170 MW) and EDF3 (375 MW) on the Chinon site; EDF4 (480 MW), which was soon renamed Saint-Laurent 1 (or SL1), and SL2 (480 MW) on another site in the Loire valley in the town of Saint-Laurent-des-Eaux; and Bugey 1 (500 MW), on a site near Lyon at the foot of the French Alps.[7] EDF owned and operated all five of these reactors. In theory, the CEA was supposed to design the "nuclear" parts of these reactors and EDF the "conventional" parts; in practice, however, each institution tried to design most of each reactor.

Competitiveness and Prestige: Engineering by Trial and Error, 1955–1959

Since the inception of the nuclear program, the notion of prestige had dominated debates between the two institutions. Both argued that a nuclear program would increase their nation's international stature. Each pushed distinct technological and political agendas to enhance its institutional prestige. Notions of prestige continued to pervade quarrels between the two institutions until the end of the 1950s. Partly because of differences in institutional goals and work habits, and partly because each institution wanted to differentiate itself from the other, engineers in each developed elaborate technological notions of what it meant to enhance the prestige of the nuclear program. The next two gas–graphite reactors were EDF2 and EDF3, both to be built at EDF's Chinon site. The main argument over these reactors focused on the amount of power that each should be designed to produce. EDF engineers wanted to make big leaps in power with each new reactor. CEA designers preferred to build reactors similar to one another in technological design.

Ultimately, the nuclear adventure would only be worthwhile for EDF if it could eventually build a reasonably priced plant. This remained a distant goal in the mid-1950s. Unable to accurately analyze the cost of a reactor, EDF viewed this goal in technical rather than economic terms. Before the construction of EDF1 was even completed, utility engineers began considering design changes for EDF2. Based on their experience with conventional power plants and observations of their British counterparts who were building increasingly powerful reactors, EDF engineers decided that they first had to increase the reactor's power. They quickly drafted a preliminary proposal in September 1956. Using 150 tons of uranium arranged in a vertical empilement encased in a spherical metal pressure vessel, and pushing the carbon dioxide cooling gas through the core at a pressure of 35 kg/cm^2, they thought they could get 100 MW out of the reactor.[8] They presented this list of parameters to their CEA counterparts for review.

CEA engineers reacted favorably to this initial proposal. In May 1957, the CEA proposed a reactor that would use 258 tons of uranium, fashioned into fuel slugs identical to those of EDF1. These would be stacked in a vertical empilement encased in a cylindrical, rather than spherical, metal vessel, with carbon dioxide flowing through the core at the lower pressure of 18 kg/cm^2. This reactor would produce 114 MW of electricity.[9]

This suggestion went against everything the EDF team considered good engineering sense. If the CEA was willing and able to supply over 100 extra tons of uranium, EDF should get more than 14 MW extra in return. Furthermore, since drafting their preliminary design, utility engineers had had numerous discussions with their British counterparts. The British had developed a fuel slug for their gas–graphite reactors that was able to stay in the reactor longer and thereby produce more energy. Although fuel slug design was the province of the CEA, EDF engineers thought that the French should at least match the British in this domain. The next meeting with the CEA was a month away. The EDF team wanted desperately to produce a counterproposal by then. Working furiously, they arrived triumphantly at the meeting with a new reactor project. This reactor would use only two more tons of uranium than the CEA's version. With this uranium stacked vertically in a spherical vessel, and carbon dioxide flowing at a pressure of 25 kg/cm^2, this reactor could produce 167 MW of electricity. This design was predicated on the CEA's ability to design a fuel slug similar to the British one.[10]

CEA designers strongly objected to this counterproposal. Above all, they wanted a reliable reactor. Although also interested in building a "better" reactor than the British, they thought that a more effective way to do so would be with a series of less powerful, yet flawless, reactors, especially since the British had just experienced a fairly serious accident with their Windscale reactor. CEA designers feared that jumping to a larger reactor would increase the chance of running into construction and operational problems. They also feared the higher fuel slug performance posited by EDF's proposal. Should the CEA fail to design adequate slugs, the reactor would have to be stopped too often for reloading. CEA engineers would then take the blame for any resulting drop in availability, which translated into energy production.[11]

EDF engineers suspected an additional motive behind the CEA's reluctance to build a more powerful reactor. Running a reactor at higher power meant that the plutonium produced by the uranium fissioning inside the core would itself fission and produce additional energy. This in turn would make it nearly impossible to extract weapons-grade plutonium from the spent fuel.[12] If the CEA had thought about this in 1957–1958, it did not say so; it seemed content with the plutonium produced at Marcoule. But EDF's suspicions were confirmed after de Gaulle's return to power and his open support of the CEA's military program.

Debates between the two design teams continued for several months, as they countered each others' proposals and tried to achieve a compromise. The EDF team pushed the power threshold even higher. It began arguing for 250 MW, the current threshold for French conventional power plants, and closer to the British level. The final design parameters, settled in April 1958, incorporated many of EDF's proposals. Still, the CEA had managed to impose some of its own requirements. The reactor core, encased in a spherical metal pressure vessel, would contain 251 tons of uranium, cooled by carbon dioxide at a pressure of 27 kg/cm^2. The reactor would use two alternators, identical to those used in conventional power plants, of 125 MW each. The figure announced to the public, however, would be 175 MW. Thus EDF could get the prestige of building a powerful reactor, and the CEA would have an error margin should it experience difficulty designing new fuel slugs.

A CEA–EDF meeting the following month to discuss the design parameters of the next reactor reopened the question of power thresholds. The EDF team announced that it wanted EDF3 to run at 500 MW, using two alternators of 250 MW each. CEA designers resisted, arguing that a 250-MW reactor would suffice; they even felt willing to publicize this figure.[13] But utility engineers countered that if EDF3 ran at 500 MW, it would be the world's most powerful reactor—not a possibility to be discarded lightly. The CEA offered a compromise at 375 MW, noting that this level would still give EDF3 that distinction, and enable it to use three 125 MW alternators like those used for conventional plants.

Before engineers could settle the question, a technological mishap introduced a new hurdle into the discussions. Early in the morning of Friday, February 13, 1959, an explosive noise at the Chinon site signaled the sudden appearance of a 10-meter-long crack in EDF1's spherical containment vessel, then in the final stages of welding. The explanation for the crack soon became clear: a newly welded piece had not yet undergone the thermal treatment required to relax the internal stress produced as the metal cooled off. The fissure occurred when the metal suddenly released the internal energy it had thus accumulated.[14] It was easier to determine the cause of the accident than to fix the problem: the Société Levivier, builder of the containment structure, had no idea what to do next. The accident received extensive press coverage and took on national proportions, and for several weeks EDF and Levivier became the laughingstock of the CEA. A solution was eventually found, but the accident pushed back EDF1's start-up date by three years: it did not begin operation until September 1963.[15]

Of more immediate consequence to EDF, though, was the public humiliation it underwent after this incident. The CEA instantly blamed the mishap on EDF's stubbornness in picking a steel, rather than a prestressed concrete, containment vessel, and on the utility's insistence on being its own "industrial architect," rather than choosing a private company for that purpose, as the CEA had done for Marcoule and encouraged EDF to do for Chinon. Some industrial and economic leaders agreed with the CEA. But not everyone blamed the accident on EDF's industrial policy. Some CEA engineers thought only that insufficient metallurgical research had gone into the vessel design. Nor did the Ministry of Industry object to EDF's industrial policy, saying rather that the utility had not adequately organized itself to deal with the development of a nuclear program.[16]

After this initial flurry of blame-casting, questions about EDF's industrial contracting policy were dropped. Apparently, the time was not right (as it would be a few years later) to challenge the utility on this point. However, the incident did raise questions about EDF's judgment. In particular, Pierre Massé, the new head of the Planning Commission (and a former EDF manager), questioned the wisdom of increasing the power of each successive reactor so dramatically. He and some of the private companies that held contracts for previous reactors thought that EDF would do better to build greater numbers of smaller reactors in order to give the builders more experience with the technology. But EDF's upper-level managers did not trust the motives of the private companies. They suspected that companies merely wanted to build more reactors so as to make more money, without caring about the long-term future of the nuclear program.[17]

Until this moment, engineers both in the CEA and in EDF made their technological choices by relying on institutional traditions. For example, EDF used its experience with conventional power plants as a reference point, while the CEA wanted to build a series of reactors as it had done at Marcoule. They defended those choices by associating both institutional and national prestige with technological achievement and sophistication. No overarching theories of reactor design guided their work: engineers in both institutions learned by doing. This meant that much of their design work proceeded by trial and error. They had no idea whether they would like a component's design until they had actually built the component, and sometimes, as in the case of EDF1's pressure vessel, they ended up regretting their choices. But the pioneer spirit that pervaded the program kept them from feeling discouraged. And as long as their work remained unquestioned by the State or the public that they professed to serve, they felt no need to change their approach.[18]

De Gaulle's accession to power, the importance he attached to the military nuclear program, his fondness for the CEA, the fact that it had not committed any visible technological errors, and its unquestioned expertise in nuclear matters meant that the agency did not have to alter its positions. But the incident with EDF1's containment vessel and the shifting political and economic climate meant that EDF had to find another way to defend itself. In the late 1940s and early 1950s, the utility needed only to pay lip service to cost-effective energy. Its most important mission was to endow France with a reliable electric network, a mission now fulfilled in large part with conventional power plants. But in the France of the late 1950s, in which other government institutions were charged with implementing specific plans aimed at fortifying industry and the French economy, EDF, as a state agency, was expected to set both an industrial and an economic example for the rest of the nation. Engineers and managers involved in EDF's nuclear program could no longer argue that as employees of a nationalized company, they naturally tended toward solutions that best served the public interest and therefore that their desire to build ever more powerful reactors inevitably represented the best course of action. In order to control reactor development and minimize the influence of the CEA, they had to find a new rhetorical strategy.

Perhaps keeping in mind Massé's fondness for precise economic analysis—during his first tenure at EDF, Massé had created the Service des Etudes Economiques Générales to study the economics of energy supply—one EDF manager suggested that the utility generate an economic study comparing the cost of copying EDF1 with that of the proposed design of EDF2. Regardless of the results, he noted, "it is easy to justify our present policy by saying that we are building nuclear plants larger than those originally planned, but further apart [in time.]"[19] The study, completed a few months later, showed that the cost of reproducing EDF2 (30 billion francs) was less than twice that of reproducing EDF1 (16 billion francs). Considering that EDF2 would produce nearly three times as much electricity as would a copy of EDF1, reproducing EDF1 did not seem worthwhile.[20]

EDF promptly began a similar study for the various design options for EDF3. Launching requests for bids in industry for a reactor that used three 125-MW alternators and another that used two 250-MW alternators, it showed the CEA and the Planning Commission that the latter solution was cheaper. The two institutions reached a compromise: they would build EDF3 with two 250-MW alternators, but they would announce a figure of 375 MW. Again, this would give them an error margin as well as the capacity to push their technology to the limit.[21]

EDF's use of these economic studies to defend its technological choices signalled the beginning of a major transformation within the nuclear division of the utility. The success with which these studies had enabled engineers to have their choices accepted encouraged them to continue using such studies and to develop and refine their techniques. Rather than designing exclusively by trial and error, EDF engineers began using such studies in their design work as well. We shall now examine the increasing role of economic analysis in engineering work, and the role that this analysis played in helping EDF engineers change the terms of debate within the nuclear program.

"L'important C'est de Convaincre"[22]: Nuclear Power Competes with Conventional Power, 1960–1964

Engineers in EDF's nuclear teams began to use economic analysis both as a design tool and as part of their rhetorical strategy just as such analyses gained widespread national attention. De Gaulle's return engendered renewed enthusiasm toward economic planning. The Fourth Plan, intended to cover the years 1962–1965, was the first elaborated under the new regime. It benefitted not just from a political and economic climate more disposed to heed its recommendations, but also from a new Planning Commissioner, Pierre Massé.

Massé had spent much of his career in electric utilities and joined EDF at its inception. Renowned both within the utility and in political circles for his formidable intellect, he was one of the men responsible for introducing economic modeling, not just to EDF but to the French industrial world. During his first tenure at EDF, he elaborated theories of economic optimization to figure out how best to handle the electricity distribution network and regulate EDF's overall system of energy production. These models won the respect of engineers and managers throughout the utility, and recognition in French private industry as well as abroad. In his new capacity as Planning Commissioner, he used his theories to generate economic models of the nation's industrial development. The precepts of the Fourth Plan rested upon these models.[23] Meanwhile, back at EDF, Massé had left a solid legacy of economic analysis, concentrated in the Service des Etudes Economiques Générales.[24]

He left this division in the hands of Marcel Boiteux, a brilliant young economist from the Ecole Nationale Supérieure. The Service's main tasks were to forecast the nation's electricity demand, analyze external factors that would influence the cost and pricing of electricity production, and prepare the management and rationalization tools that corresponded to Massé and Boiteux's ideas about economic optimization. Typically, the division developed consumption forecasts for five to ten years in the future. These forecasts were then used to justify current construction of power plants. Prediction of France's overall energy demand would be based on the gross national product (GNP) forecasts publicized by the Planning Commission. At first, according to one of Boiteux's employees, the division used classic econometrics models that posited the growth of energy consumption to be a function of the expected rate of growth of the GNP.[25] When Pierre Ailleret, EDF's Directeur Général Adjoint, began to examine the question, he argued that uses for electric power were developing so rapidly that consumption would in fact increase geometrically rather than linearly; he predicted that it would double every ten years. This "doctrine," to use Ailleret's term, began to underlie the models generated by the division.[26]

Initially, these economic studies were directed less toward developing accurate forecasts of energy demand than toward convincing those outside EDF that demand would in fact rise. As Boiteux told one of his economists, "l'important c'est de convaincre" ("What is important is to convince others."[27] The Service des Etudes Economiques Générales thus provided EDF's project engineers with the tools they needed to "sell" their work. And there was no question that these tools had persuasive power. Perhaps because it was headed by Massé, a primary architect of these tools, the Planning Commission readily accepted the validity of EDF's analysis. More important still, these analyses often persuaded the Ministry of Finance to uphold EDF's budget allocations—a crucial accomplishment, as the ministry had the power to cut costs and slash programs when it deemed such actions necessary. A high-ranking official of the Ministry of Industry later recalled that:

> EDF was . . . one of the first big enterprises to have done in-depth techno-economic [*sic*] studies. It is important to underscore this point, as they were very much appreciated by the [Ministry of] Finance. . . .[28]

Perhaps in part because of their persuasive power, the influence of such economic studies extended beyond the rhetorical spheres of ministerial politics into engineering practice. By 1960, the studies of the Service des Etudes Economiques Générales comparing the price of different forms of electricity production had circulated throughout the utility. Ailleret, known as a staunch advocate for nuclear energy since the early 1950s, became a great proponent of these studies as well. He headed EDF's Comité d'Energie Nucléaire, a committee that met once a month to discuss the utility's nuclear development policy and examine current technological problems or choices in the reactor program. His background as an engineer of the Corps des Ponts et Chaussées and his involvement in the CEA's Marcoule projects doubtless gave him credibility. It seems likely that engineers in charge of EDF's nuclear program began using the techniques of economic analysis at least in part through his influence.

Economic analysis, in the form of "optimization studies," had been used for several years elsewhere at EDF in designing conventional power plants. These studies broke down the cost of a power plant into the cost of its individual components, then minimized the overall cost either by finding ways to lower the cost of specific components or by redesigning certain components so that the whole plant would produce more power. These methods were not applied to reactor design until 1960, however, partly, perhaps, because "optimization" did not become popular in EDF until then, and partly because the number of variables to take into account when analyzing reactors was so high that calculations were extremely difficult to perform with mere adding machines. The arrival of computers in EDF's research facilities changed the latter state of affairs.[29]

The first optimization study done for reactors covered the design of EDF3 and was performed in the first half of 1960, before the final design parameters had been set.[30] The principle guiding the optimization of EDF3's design was to maximize power while minimizing the volume of the reactor core. Using reference costs provided by the Service des Etudes Economiques Générales and relationships between various core dimensions, engineers could play with different core configurations to calculate how to derive the most power from the least uranium. They could thus "prove," for example, their assertion that increasing the unit power of a nuclear plant decreased the overall cost of producing electricity. Using parameters provided by various CEA teams—such as the maximum temperature of the carbon dioxide cooling gas that the fuel slugs could withstand—they also played with the parameters of the thermal cycle. Whereas in earlier projects they had only tried to make the reactors thermodynamically efficient, they now began searching for economic efficiency as well.[31]

Using optimization studies thus changed the way in which EDF engineers did their work. In the words of one engineer who worked on EDF's nuclear project both before and after the introduction of these studies, before, "the whole trick . . . was to find the best compromise possible, without much economic data. We didn't do any optimizations. . . . It was a mixture of common sense, of intuition. . . ."[32] Once they began using optimization techniques and computers:

> Until then these calculations were done by hand. I had a young woman engineer with me [who did most of these calculations]. . . .
>
> At the time, the people behind the computers wore white coats. [They] took your calculations, a bit like a doctor would see you for a visit. . . . The machine put out for me in one run what the young woman engineer would have taken two years to do. . . . We could "play" in a much more sophisticated way. . . .[33]

Engineers soon began to plug technological options into economic models in order to test which option would best suit their purposes. Economic modeling, from optimization studies to energy consumption forecasts, became a trademark of EDF. Pioneered in the utility, these techniques became something that the whole institution grew proud of, and that marked the work done there, at least during the 1960s, as unique. Although these methods of working spread to a few other industries, EDF economists and engineers remained the acknowledged experts in the domain.[34]

Optimization studies did not set the goals of EDF's engineers, but their use influenced both those goals and the path that engineers took to attain them. As nuclear design teams began to use optimization studies in designing reactors and justifying their solutions, they became more caught up in the practice of economic comparisons. Initially, engineers compared the cost of their reactors with that of conventional power plants in order to show those outside EDF that they aimed to produce a technology that would soon be economically viable. But very quickly such comparisons began to dominate their work. In the words of one participant, "we lived in economic comparisons, in comparisons of the cost of the kilowatt-hour."[35] This comparison provided them with a new agenda, one as economic in nature as it was technological.

The use of economic optimization studies heightened the awareness of EDF's nuclear teams that their work had to fit into a larger system of electricity production. They had always wanted their plants to produce electricity at the minimum possible cost, but in the 1950s, the mere fact of building such a novel technology had provided them with a sufficient raison d'être. Furthermore, they had billed their reactors as "prototypes": no one had expected the first reactors to be economically viable. The government had even been willing to pay a *surprix,* a surplus cost for the reactors, on the chance that nuclear plants would eventually provide France with an independent energy source. Given their new tools, however, and given the political and economic climate of the early 1960s, these engineers began to realize that in order to survive, they not only had to compete with the CEA for jurisdiction over plant design, but also with their colleagues in conventional power—not just technologically, but also economically. They began furiously analyzing the "objective cost" of their projects, from EDF1 through EDF3, in order to get a sense of how close they were to producing a nuclear kilowatt-hour (kWh) that could "compete" with the conventional one.[36]

Their results indicated that they could achieve this goal with their next reactor, EDF4, destined for a new site in Saint-Laurent-des-Eaux. This time, however, they decided that rather than increase the power of the reactor, they would design a 480–500-MW reactor primarily geared toward "competitiveness" with conventional power plants.[37] They rejected the CEA's idea of copying EDF3's design, preferring instead what they called an "integrated" design. In this configuration, the heat exchangers sat inside the pressure vessel, right underneath the core. This new design, they felt, would save on construction costs and increase the safety and reliability of the reactor.[38] Because the reactor would probably last longer than the Chinon reactors, they planned to extend its amortization period, thereby reducing their initial payments.[39] And finally, they would design EDF4 solely for electricity production.[40] They had attempted to design EDF2 and EDF3 on these terms, but the CEA had managed to impose certain design features that facilitated the production of weapons-grade plutonium and reduced the amount of electricity that the reactors could generate.[41]

The debate over plutonium production in the early 1960s provides perhaps the most striking example of the increasing prevalence of economic reasoning and the change in ideas about competitiveness in the thinking and rhetoric of EDF engineers. In the 1950s, EDF engineers had cast their objections to plutonium production primarily in technological terms: this production would alter reactor design in a way undesirable for electricity production. But in 1960 they began casting their objections in economic terms as well, thereby changing the nature of the plutonium debate. In order to understand how this happened, we shall examine this debate in some detail.

The CEA did not dispute that nuclear plants should become "competitive" with conventional ones, even though it did not always agree with EDF's views on the best way to attain this goal. But it remained extremely interested in obtaining weapons-grade plutonium from EDF reactors, especially as de Gaulle's *force de frappe* agenda permitted the expansion of its military program. In 1960, it made its first official request for plutonium to EDF. Needless to say, engineers at the utility were less than thrilled by this request, but after extensive discussions between the Ministry of the Armies, the Ministry of Atomic and Space Affairs, the Ministry of Industry, and the CEA, the utility gave in. In December 1960, EDF told the CEA that it did not oppose providing the subirradiated fuel slugs necessary for plutonium production as long as the utility did not have to bear the extra expense of doing so, and as long as the experience that EDF hoped to gain out of operating the Chinon reactors was not impaired.[42]

As of February 1961, the official arrangement was that unless an unforseen incident took place at the Marcoule reactors, no more than one-sixth of the fuel capacity of the Chinon reactors would be used for military purposes, and this only as of 1966. In April 1961, however, the CEA asked for a higher limit: they wanted to use one-quarter the fuel capacity of the Chinon reactors for plutonium production. Both EDF and the Ministry of Industry protested this change, arguing that it would seriously impair EDF's ability to derive adequate operational experience from its own reactors. After further negotiations, the terms of the agreement were redrawn in April 1962. The CEA would give EDF a set number of specially designed fuel slugs reserved for plutonium production; it would pay for changes that EDF had to make in the fuel loading machines of both EDF1 and EDF3 to facilitate this production; the two institutions would agree on a definition of the maximum load destined for each type of fuel slug in each reactor; and finally, both institutions would evaluate the "inconveniences" caused in the operation of the reactors by plutonium production and come up with compensatory measures.[43]

Because the nature of those compensatory measures remained unclear, EDF engineers were able to use their newly found expertise in "technoeconomic" analysis to redefine the plutonium question in economic terms. EDF's Comité de l'Energie Nucléaire considered several ways of turning plutonium production into an economic problem. Initially, the CEA acknowledged that the plutonium was destined for weapons use. EDF would therefore derive no benefit from its production. Hence, concluded the Comité, it should calculate the financial loss EDF would suffer by figuring out the equivalent energy that a coal plant would produce.[44] But around 1962, the CEA began talking about civilian uses for plutonium. It had begun to work on Rapsodie, its first experimental breeder reactor, which ran on plutonium. The CEA argued that Chinon's plutonium could potentially go to Rapsodie, and eventually to future breeders. As these breeders would generate electricity, it was hence in EDF's financial interest to produce plutonium. Undeterred, EDF engineers calculated the financial benefit that the CEA would derive from treating the used fuel, arguing that this benefit had to be considered in the price that EDF might eventually pay for breeder fuel. The spent fuel went to CEA reprocessing centers, where the plutonium would be separated from the uranium for future use. The cost of this operation, EDF argued, was diminished by the monetary value of the plutonium. In response, the CEA noted that starting up a reactor, which EDF had to do no matter what, inevitably led to the production of certain amount of plutonium, known as "fatal" plutonium. This should be taken into account in any economic calculation made by EDF. EDF responded that it could easily devise a fuel loading cycle that would not produce "fatal" plutonium. Besides, the committee argued, "given the impossibility of predicting how the problem of military plutonium will be posed, right now it is not a question of proving anything, but of determining very objectively the different losses of information that could result from the presence of subirradiated fuel. . . ."[45] This determination was necessary both to facilitate the design of the next reactor, and to estimate the economics of future reactors. Engineers thus attached a specific financial value to their technological agenda.

This line of reasoning, together with the increased importance of producing a "competitive" kilowatt-hour, led the Comité to the idea of a plutonium credit as one possible way of making EDF's reactors more cost-effective:

> A plutonium credit with the CEA now appears possible. We would then go back to the formula of a "meter" according to which EDF would offer the CEA a recuperation price. This would be a function of the amount of plutonium present, EDF being free to operate [reactors] in the best economic conditions, which would result from the leeway involved in the "meter."[46]

Just as EDF could not outright squash the CEA's demands for military plutonium,[47] neither could the CEA deny the desirability of EDF's goal of a competitive nuclear kilowatt-hour. It did, however, argue that a plutonium credit would not help EDF attain this goal. The CEA had started a small division of economic studies whose economists appeared mainly concerned with refuting EDF's figures. They soon produced several reports directed at invalidating the concept of a plutonium credit. These studies concluded that a plutonium credit would in no way help the nuclear kilowatt-hour compete with the conventional one. On the contrary, such a credit might even set such an effort back. Rather, they argued, the concept of a plutonium credit should be set aside for a while and economic analyses should be devoted to studying the mechanisms of the creation and development of a worldwide plutonium market.[48]

In typical fashion the issue went back and forth between the two institutions for some time. The debate dragged on through 1964, when its terms were altered by a new definition of competitiveness that had begun to receive serious attention on the national political and economic front: the economic competitiveness of French technology on foreign markets. Once again, EDF tried to change the terms of the debate:

> The competition that our system is likely to encounter in the near future from the boiling water system leads us to reconsider the hopes of assigning a value to irradiated fuel [raised by] the prospect of breeder reactors.
>
> Despite the interest rates and the possibilities of liberating plutonium, it seems that preparing a bill for breeders gives an economic interest to the preparation of a stock of plutonium. This interest should translate commercially into a "plutonium credit" *on the order of magnitude of the differences in cost between the French system and the American system*[49] [emphasis added].

This new approach to economic competitiveness, which compared French technology with foreign technology rather than domestic nuclear plants with domestic conventional plants, soon began to dominate the debates between the two institutions, making them more acrimonious than ever. The dimensions taken on by new debates over exporting reactors eventually obscured the whole issue of the plutonium credit, as EDF's policies were called into question and the government's stake in the nuclear program rose yet higher.

The Organization of Industrial Contracting: French Reactors Compete with Foreign Technology, 1964–1969

The arrival of the Common Market in the late 1950s focused the attention of government leaders on preparing their country for new economic conditions. They were especially concerned with French industrial structure and development. Many felt that, despite the intensive development of the reconstruction, French industry still lagged behind that of other developed nations. Some argued that French industry had spread itself too thin by trying to develop competence in too many different domains of technology. To remedy this, France should concentrate on specializing in a selected number of high-technology fields—of which nuclear energy was one.[50] Others argued that industry had spent too much time on product development and not enough time on long-range corporate strategies.[51] Georges Pompidou, de Gaulle's second prime minister, felt that the source of these problems lay in the protectionist policies and economic restrictions that had characterized French economic structure in the preceding decades. The solution lay in taking measures to decrease the hold of the state on French industry, thereby liberalizing the economy. In true French style, this attempt to open the economy was formalized in the State's Fifth Plan, elaborated by the Planning Commission in 1965. This plan aimed at combatting the inward focus of French industry and helping the French economy prepare for the competition it had already begun to face from foreign nations. Its biggest priority was "to establish the competitive capacity of French industry in the world."[52] But how should restructuring of French industry occur? Should French companies form large consortia that could compete on a European scale? Or would competitiveness on foreign markets work better if domestic competition were allowed to thrive? This national debate addressed issues at the heart of EDF's nuclear contracting policy.

Throughout the first half of the 1960s, EDF had smooth relations with the government. The only area in which the utility had any trouble was plutonium production. Otherwise, though, government institutions had supported its decisions and programs. The Ministry of Industry regularly defended EDF's interests; the Ministry of Finance had approved its plans; the Planning Commission, headed by a former EDF economist, appeared to hold a vision of France's economic future compatible with EDF's; and Comité pour la Production d'Energie d'Origine Nucléaire, or the PEON Commission, ostensibly in charge of elaborating programs for nuclear energy development, had approved EDF's proposals.[53]

EDF's easy relationship with the government would not continue. As the government's determination to look beyond the boundaries of the French state found echoes throughout the nuclear program, various issues once again challenged EDF's vision of nuclear development. In this round of debates, utility engineers had more difficulty defending their positions, partly because technological problems with EDF3 had damaged their credibility,[54] partly because the joint forces of private industry, the CEA, and various government institutions were arrayed against them, and partly because EDF engineers had lost the unconditional support of their managers.[55] Once again, aspects of the organization of technological work at the utility in the context of a new definition of competitiveness.

In 1964, exporting French reactors had begun to seem plausible to certain members of the nuclear establishment. How to build exportable reactors, however, remained an open question. Jules Horowitz, head of the CEA's Direction des Piles Atomiques argued that in order to export this technology, France would have to concentrate solely on building a reproducible product. Thus he tried to convince his EDF counterparts to copy EDF3's design in future reactors. Most EDF engineers strongly disagreed. One expostulated:

> What would be the position today of the CEA supporters of export if EDF had adopted Mr. Horowitz's point of view? EDF3 would be limited to 375-MW gross, [and] EDF4 would be a duplication of EDF3, which is to say a design completely surpassed by the British projects at Olbury and Wylfa.[56]

By the mid-1960s, though, not everyone at the CEA advocated building reactor series. In an effort to make peace between the two institutions so that they could work together more fruitfully, Robert Hirsch, the CEA's Administrateur Général, wrote to André Decelle, EDF's Directeur Général, that "the French efforts to export" led the CEA to consider the development of an improved version of EDF4 an urgent matter. The CEA, Hirsch wrote, was conscious of the increasing pressure of foreign competition and was willing to undertake the research necessary to push French reactor design as far as possible.[57] Decelle received this suggestion favorably, and the two leaders drew up informal cooperation guidelines. Thus the issue of international competition entered nuclear debates. It even seemed as though the two leaders agreed over both the need to conquer this new challenge and the means with which to do so. But this truce did not last long.

By mid-1965, engineers and managers had begun quarreling again. This time, their confrontations were not about how to design reactors; Hirsch and Decelle had at least managed to still those quarrels. Rather, the source of conflict was EDF's industrial contracting policy. The two institutions had argued briefly about this policy in the mid-1950s; the issue then lay dormant for nearly ten years. When it came up again in the mid-1960s, it was discussed with more venom, and, it seemed, with more at stake, for it related directly to questions about France's role in the international market.

The fundamental problem remained the same as before, only this time private industry had accumulated more construction experience with the nuclear program. Throughout the construction of its reactors, EDF had relied on a single, time-proven method of industrial contracting. One of several teams in the Direction de l'Equipement played the role of both *architecte industriel* and *maître d'œuvre* for a given reactor. Thus the team would devise an initial design for the entire reactor, subdivide various components into lots, launch requests for bids among private companies for each lot, pick the best bid, and supervise and coordinate the construction of the reactor. For its Marcoule reactors, the CEA had merely come up with the initial design; it then picked one industrial consortium to do all the rest, although of course the CEA teams followed the building process attentively and provided technical help to companies that ran into any problems. The CEA had raised strong objections when EDF proceeded differently.

EDF held that its method provided the best means of obtaining the lowest prices on components, and the debate subsided. In 1965, however, in the face of new questions about France's international "competitiveness," EDF's policy came under renewed attack. The companies that had been building EDF's reactors were unhappy because they felt that the policy did not allow them to get the experience they needed to successfully export reactors. Because no single company had had the opportunity to coordinate the construction of an entire reactor, none could actually sell a reactor to a foreign country. At best, they could put in bids for reactor parts. But the organization of nuclear programs in other countries differed substantially from that in France, and the opportunities to put in such bids were rare to nonexistent.

EDF defended itself by rephrasing its arguments in popular political terms. Its method would "make possible wider competition," as well as enable the utility to pay less surplus cost on its reactor. This, in turn, would "favor the competitiveness" of the gas–graphite design with other designs.[58] Realizing, however, the difficulties that its policy posed for companies wishing to export reactors, EDF engineers were willing to make slight changes. For the construction of the Saint-Laurent and the Bugey reactors, it encouraged private industry to create consortia that EDF could then contract to work on larger subdivisions of the reactor. For the case of Saint-Laurent 1, for example, this meant that only 17 orders were filled for over 80 percent of the reactor. Thus competition would continue to exist between two sets of consortia. But it also meant that EDF had to keep a closer watch on private industry to avoid cost overruns. This seemed as far as the engineers in the EDF teams were willing to go.[59]

Private industry and the CEA wanted to push EDF further. It wanted EDF to launch bids for what came to be termed "chaudières nucléaires," or "nuclear boilers." In this scenario, once an EDF team had drafted a preliminary design, it would accept bids from large consortia for the reactor core and attending machinery as a whole. This suggestion did not sit well with the engineers in the EDF teams. One wrote angrily:

> Increasingly one hears, and especially in high spheres, closer to Politics than to Industry, that EDF is not fulfilling its normal [*sic*] role with respect to French Industry, and in particular that the division of contracts that it passes prevents the birth, or impedes the growth, of powerful [industrial] Groups, the only ones capable, it appears, of exporting plants to foreign countries.
>
> This affirmation, so often repeated that it is taking on the allure of dogma, is but a vulgar untruth.[60]

The issue had arrived back on the level of the mission of a public institution to its State. EDF engineers, proud of their work, felt offended by attacks on their competence and judgment in fulfilling their mission. They argued that the division of labor between various companies had never posed a problem: the problem was, rather, with industry as a whole. On numerous occasions, EDF had had to help companies solve technological problems that they were incapable of dealing with independently. It was not fair, argued EDF engineers, to compare the "nuclear boilers" with the boilers in a conventional plant: "nuclear boilers" represented a full 70 percent of the entire plant, whereas conventional boilers made up only 25 percent of the plant.

One engineer pursued his defense of EDF's policy by noting that the utility's mission to the country was to provide the nation with electricity in the best possible cost and safety conditions. This could only occur if reactor construction could benefit from all the experience accumulated by the Direction de l'Equipement, and if engineers could continue to choose the best material at the lowest price. And the French reactor program would be in an even better position if industry would accept free-market competition rather than organizing itself into syndicates and lobbies whose power obstructed progress by killing any proposals that might jeopardize the existence of such entities. "The attitude of French industry," wrote this engineer, "despite a few rare and brilliant exceptions, is a defensive attitude, the role of its [leadership] being to build a 'Maginot line' around more or less sanely arrived-at positions."[61]

Currently, he continued, industry organized itself into loose associations of companies that became weakened rather than strengthened by such associations:

> . . . we think that the fusion of, or the understanding between, two Companies working in the same field can be worthwhile, while as the grouping, under the banner of a bank . . . is a grotesque effort and unfortunately dangerous, because, for many of our leaders, volume and power go together with intelligence, as if the diplodocus hadn't been dead since the secondary Era![62]

Such groupings diffused the technological knowledge and experience that resided in the companies rather than fusing such knowledge together. Rather than go along with such groupings, EDF should promote those that would make French industry strong on the international market. In conclusion, he wrote:

> The Commissariat à l'Energie Atomique, spokesman of the "Groups," reproaches EDF for a policy which, apparently prevents French Industrialists from exporting anything. . . .
>
> First, one must have something to export; whether one wishes it or not, as long as we cannot offer, in France, nuclear plants that function normally and give their user, that is EDF, full satisfaction, only political pressure or exhorbitant financial advantages can lead to the export of nuclear plants. . . .[63]

Many engineers in the Direction de l'Equipement felt the same way, even if none expressed himself quite so eloquently. Many sincerely believed that their method of working was truly the best one for the overall health of the French economy. But one of them expressed the most probable fundamental reason for their vehemence: if industry took over larger portions of the work of designing and building reactors, EDF engineers would not have much interesting work left.[64]

This time, unlike in the mid-1950s, the contracting issue reached the ministerial level. The whole issue of industrial competitiveness had become the single most important economic question in the nation. Furthermore, private industry had joined the CEA in attacking EDF's policy. And in the mid- to late 1960s, politicians felt less inclined to blindly trust EDF.[65]

EDF engineers fought hard to preserve their working methods, arguing that only thus could reactors become both technologically and economically suitable for export. For example, one engineer argued that even if industry formed two consortia, as it had done, the Direction de l'Equipement would not truly have a choice between them, since one of the consortia, Groupement Atomique Alsacienne Atomique (GAAA), had recently lost a contract with the Germans and would need a consolation prize in the form of a reactor contract. Furthermore, he argued, the CEA was unfairly balancing the odds to favor the policy advocated by industry. While the project costs were all that counted in the eyes of many, for EDF engineers the safety and reliability of the installations counted equally. Such concerns explained the surplus cost of EDF reactors. He continued:

> Who will decide between these two points of view? The CEA? I don't think so. I point out on this subject that EDF never got more than 445–450 degrees [centigrade] out of the CEA for the temperature of the fuel slug cans. But [the CEA] immediately gave Industry 465 degrees [centigrade] to make the system competitive for export.
>
> . . . When an accident or a breakdown occurs, if it occurs one day, ten or fifteen years may have gone by. GAAA and Schneider will have disappeared, and EDF will find itself alone before its judges.[66]

The top managers of EDF's Direction de l'Equipement, however, appeared unwilling or unable to decide in favor of their engineers. By the mid-1960s these managers were primarily career administrators or economists rather than engineers.[67] Perhaps the pressures put on EDF by the government and private industry were too strong to resist. In any event, at the end of December 1965 the Direction made a tentative decision in favor of a new contracting policy for the reactors at Fessenheim, the projected site for the next two gas–graphite reactors. EDF would launch two kinds of requests for bids: one set would follow the utility's traditional policy, and the other would call for bids on the "nuclear boilers."[68]

This proposal assuaged private industry, the government, and the CEA, but it angered the engineers at EDF. They continued to write memoranda and reports to persuade the Direction to reverse the decision.[69] The labor unions also expressed their objections. Claude Tourgeron, the Confédération Générale du Travail's (CGT)[70] representative to EDF's Conseil d'Administration (board of directors), argued that the new policy was bad for the nuclear program, bad for EDF, and bad for the nation. The companies submitting bids for the smaller sublots in the traditional request for bids, said Tourgeron, belonged to the consortia that would submit bids for the "nuclear boiler." They would play with the numbers so that the consortia bids would appear, artificially, lower than the sum of the individual bids. Were the Fessenheim decision merely an experiment in alternative bidding, that would be all right. But Tourgeron suspected that such was not the case: one thing would lead to another, this mode of bidding for nuclear plants would continue, and since the plants of the future would be predominantly nuclear, this policy would eventually put the vast majority of the Direction de l'Equipement's employees out of work. Finally, Tourgeron argued, it was unrealistic to think that France could ever really export gas–graphite reactors. Underdeveloped countries would not want nuclear plants because they were only profitable when they were very powerful, more powerful than such countries would ever need. And industrialized countries would clearly want American plants, as the figures showed these to be less expensive. Gas–graphite plants made sense for France because she had her own natural uranium supply, Tourgeron argued, but they did not make sense for anyone else. Thus the two consortia proposed would only have one customer: EDF. This situation would clearly accelerate the demise of the Direction de l'Equipement, and artificially affect the cost of nuclear power plants.[71]

The objections of the rank and file at the Direction de l'Equipement were to no avail. At a meeting of the Direction in mid-February 1966, director Jean Cabanius expressed his support for the concentration of industry into a few consortia, although he felt that the formation of a single French consortium for any given sector of industry should be avoided. Marcel Boiteux also favored industrial concentration, pointing out that if individual consortia did form, they could then compete more effectively on the international market. A few others had more reservations, but the final decision was made in favor of launching a twofold request for bids for Fessenheim.[72]

It appeared as though EDF's new leaders had, perhaps for the first time, surrendered to the position articulated in the Fifth Plan. Indeed, the plan's Rapport Général de la Commission des Industries de Transformation had emphasized "the need of pursuing the effort of . . . the concentration of French industry to increase its competitiveness and allow it to confront the powerful foreign companies as economic openings occur."[73]

In retrospect, some EDF managers have argued that the shift in emphasis within the nuclear program from competitiveness with conventional power plants to competitiveness on foreign markets and the bitter conflicts that ensued put the seal of death on the gas–graphite program. When the Fessenheim bids came in, EDF judged them all too expensive and refused to begin construction of the reactors. Its managers had been trying to escape the increasing interference of the CEA, to which end they had seriously considered abandoning gas–graphite reactors altogether, buying an American license, and pursuing the nuclear program with light-water reactors. The quarrel over this issue became known as the *guerre des filières* (the "war of the systems"). It was one that EDF eventually won, largely by biding its time and imposing its views on the government. That, however, is a different story entirely.[74]

Conclusion

Our story shows that the term *technological competitiveness* can take on different meanings depending on technological, political, economic, and cultural conditions. In the French nuclear program of the 1950s and 1960s, the term had three different meanings. In the 1950s, "competitiveness" had a technical meaning. Engineers in both the CEA and EDF mainly wanted to forge as "advanced" a technology as possible for their country. Both used the technological performance of the British nuclear program as a standard of comparison. For EDF, this meant building ever more powerful reactors; for the CEA, it meant building reactors similar to one another in design, but guaranteed to work. Each claimed that its agenda would reinforce the country's prestige through technology, and in both cases engineering methods of intuition and trial and error went hand in hand with the rhetorical and strategic emphasis on prestige.

These methods and strategies worked well for both institutions until the end of the decade, when technical mishaps and a changing political and economic climate combined to cast doubts on EDF's position. Utility managers recovered from their losses by changing the terms of the debate: they adopted economic modeling and forecasting techniques as a rhetorical strategy to convince government and industrial leaders of the worth of EDF's development strategy. Adopted and adapted by engineers in the nuclear program, these techniques changed the nature of engineering work in the utility. With the change in work methods and defense strategy came a change in goals. In the early 1960s utility engineers spoke primarily of making nuclear energy "competitive" with conventional power sources. The optimization techniques that engineers used, together with the economic reports that utility managers used to defend their program in ministerial and planning circles, gave the utility a unique institutional identity. Faced with this powerful array of technological, political, economic, and cultural resources, and the concomitant strength of this new definition of "competitiveness," engineers in the CEA could do little but accept the development strategy advocated by the utility. Because it had de Gaulle's backing, the CEA could insist that the utility produce plutonium, but the persuasive power of EDF's economic arguments in the early 1960s enabled the utility to change the terms even of the plutonium debates.

The rapidly changing political and economic climate soon posed a threat to the utility's newfound security, however. Economic planners, industrial leaders, and high-level government officials began to set their sights on opening the French economy to foreign competition. CEA engineers, who had not adapted their work methods to EDF's new emphasis on economic competitiveness, seized this opportunity to attack a different aspect of the organization of technological work in the utility: it charged that EDF's industrial contracting methods made the exportation of French nuclear technology impossible. Sticking to its own definition of competitiveness, the utility tried to argue that only *its* methods could make nuclear reactors competitive with conventional power plants, and therefore competitive for export. But this time, the array of forces ranged against EDF was too strong. The CEA had the backing of many of the private companies that had built reactor components, as well as of government planners and other leaders, and EDF managers, eager to maintain good relations with the government and extend the utility's purview, compromised on the contracting issue against the will of their engineers and technicians.

Elsewhere, I have explored links between technological design and the spheres of politics and economics in the French nuclear program.[75] Historians and sociologists of technology have shown that such links exist in all areas of technological development.[76] But as these same scholars would argue, technology is more than artifact, more than design: it includes entire systems of political, economic, and cultural networks. The story told in this chapter shows us that in order to understand technological development we should look even further than the links between design and politics, economics, and culture. Indeed, by looking at the organization and practice of technological work, we see that it is not just design and development that is influenced by and influences such networks, but also the way in which engineers work.

By looking at the ever-changing relationships between engineering work and the spheres of politics, economics, and culture, we can achieve a fuller understanding of the importance of and meaning attached to a technology in a given cultural context. In the particular case of the French nuclear program, the prestige of the project (a prestige conferred upon it by de Gaulle's ambitions, but also forged and reinforced by the rhetorical and cultural strategies of its architects), together with the close ties that existed between CEA and EDF leaders and government leaders (ties that grew out of both the structure of the engineering profession in France and the prestige of the project), meant that debates about the program's future became national debates. The importance of the nuclear program to the French government had political, economic, and industrial dimensions. The program had become symbolic of the nation's international stature. It was thought to ensure France's future energy independence, and hence have substantial influence on the nation's economy. And finally, the complexity of the technology meant that it required technological development in many different domains: mechanical engineering, electrical engineering, civil engineering, metallurgy, and more. The nuclear program therefore involved a wide cross section of French industry. Under such conditions, it was not just the function of the technology that was important—not just, for example, whether a reactor produced energy, or weapons-grade plutonium, or both—but also how engineers designing that technology worked. The structure of engineering work within the program was not only thought to set an example for the rest of French industry, it also became emblematic of French engineering as a whole. Thus the organization and practice of engineering work within the program became crucial, at least symbolically, to France's success in the emerging world of high technology.[77]

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Notes

1. See Jean Bouvier *et al.*, *Histoire économique et sociale de la France. Tome IV: L'ère industrielle et la société d'aujourd'hui* (Paris: Presses Universitaires de France, 1982); also Jean-Claude Asselain, *Histoire économique de la France du XVIIIe siècle à nos jours. Tome 2: De 1919 à la fin des années 1970* (Seuil, 1984).

2. François Caron and Jean Bouvier, "Les agents: l'Etat," in Bouvier *et al.*, *Histoire économique et sociale de la France*, op. cit.; Bernard Cazes, "Un demi-siècle de planification indicative," in eds. Maurice Lévy-Leboyer et Jean-Claude Casanova, *Entre l'Etat et le marché: L'économie française des années 1880 à nos jours* (Paris: Editions Gallimard, 1991); John H. McArthur and Bruce R. Scott, *Industrial Planning in France* (Boston: Division of Research, Graduate School of Business Administration, Harvard University, 1969). The role of the plan in French economic policy and development has engendered much debate among social scientists since the 1960s. Some scholars, in emphasizing the distinction between the government and the State in France, argue that even during the Fourth Republic, the Planning Commission, as an agency of the State, provided political continuity despite frequent changes in government. Hence the plans should be understood as the true expression of French economic policy. Other scholars, in paying closer attention to economic practices than policies, argue that despite any continuity that the Planning Commission may have provided, government upheavals did influence the degree to which the plans were heeded. Hence it is the influence of the plans, rather than their content, that should be taken into account when analyzing their role. Although this chapter does not directly address these scholarly debates, I should note that my concern with industrial practice has led me to rely on the body of literature representing the latter position in these debates.
3. Maurice Larkin, *France Since the Popular Front: Government and People, 1936–1986* (Oxford: Oxford Univ. Press [Clarendon], 1986).
4. This is not to say that no one opposed his return, but in 1958 he had by far the strongest base of support of any politician. See Larkin, *France Since the Popular Front*, op. cit., also Philip M. Williams and Martin Harrison, *Politics and Society in De Gaulle's Republic* (London: Longman, 1971).
5. Cazes, "Un demi-siècle," op. cit., and McArthur and Scott, *Industrial Planning*, op. cit.
6. The early years of the nuclear program are discussed in more detail in Gabrielle Hecht, *The Reactor in the Vineyard: Technological Choice and Cultural Change in the French Nuclear Program, 1945–1969* (Ph.D. dissertation in History and Sociology of Science, University of Pennsylvania, Philadelphia, 1992).
7. The megawatt figures given are those announced by EDF for each reactor at the time of construction. In addition to these gas–graphite reactors, the two institutions designed another gas–graphite reactor, which they sold to Spain, and built one heavy-water reactor. The French also collaborated with the Belgians in building a light-water reactor at Chooz.
8. RETN1, BS/JCr, "Memento pour la réunion du 17.7.57 sur EDF2," July 15, 1957.
9. Ibid.
10. Ibid.; interview. The interviews referred to in this chapter are with EDF employees who worked on the nuclear program in the 1950s and 1960s. Most of them were conducted by the author in Paris between September 1989 and August 1990. Three of them are courtesy of Jean-François Picard and Alain Beltran, and were conducted by them between 1981 and 1984.
11. Georges Lamiral, *Chronique de 30 ans d'équipement nucléaire à EDF* (Paris: Association pour l'Histoire de l'Electricité en France, 1988), pp. 38–39.
12. Ibid., p. 120; interview. Weapons-grade plutonium was that element's 239 isotope. Pu-239 was produced in a reactor when a U-238 atom absorbed a neutron and decayed, first into U-239, then into Pu-239. If the Pu-239 stayed in the reactor long enough, it would absorb the neutrons produced by the fissioning of the uranium and decay into Pu-240 and

Pu-241. These isotopes were undesirable for weapons-grade plutonium, as they could cause the plutonium to spontaneously fission. They were also impossible to separate from the Pu-239 in the spent fuel. Therefore the CEA wanted to remove fuel from the reactor as quickly as possible, whereas EDF wanted to leave it in as long as possible in order to extract as much energy as possible from the spent fuel.

13. Interview.
14. Interviews; Lamiral, *Chronique*, op. cit., p. 47.
15. Interviews; Minutes of the meetings of EDF's Comité d'Energie Nucléaire, 1959; Lamiral, *Chronique*, op. cit., pp. 47–51.
16. Interviews. Jean-François Picard, Alain Beltran, and Martine Bungener, *Histoire(s) de l'EDF* (Dunod, 1985).
17. Minutes of meeting of EDF's Comité d'Energie Nucléaire, June 12, 1959.
18. Interviews.
19. Minutes of meeting of EDF's Comité d'Energie Nucléaire, June 12, 1959.
20. Minutes of meeting of EDF's Comité d'Energie Nucléaire, November 16, 1959
21. Minutes of the meetings of EDF's Comité d'Energie Nucléaire, 1958–1960; Lamiral, *Chronique*, op. cit., p. 41; interviews.
22. "What is important is to convince others": the words of Marcel Boiteux to one his employees. Interview.
23. Cazes, "Un demi-siècle," op. cit.; Caron and Bouvier, "Les agents," op. cit.
24. Massé created this division in 1955. It depended directly on the Direction Général (rather than on one of the three big Directions: Equipement, Etudes et Recherches, and Production et Transport). For more on Pierre Massé and his economic thought, see his autobiography: Pierre Massé, *Aléas et Progrès: Entre Candide et Cassandre* (Paris: Economica, 1984); Pierre Massé, *Le Plan ou l'anti-hasard* (Paris: 1965), a book on the Planning Commission that Massé wrote toward the end of his tenure as Planning Commissioner; Picard, Beltran, and Bungener, *Histoire(s)*, op. cit.; Robert L. Frost, *Alternating Currents: Nationalized Power in France, 1946–1970* (Ithaca, N.Y.: Cornell Univ. Press, 1991).
25. Interview. The elasticity coefficient, an expression of the ratio of energy use to the GNP, was set almost at 1. During the interview, this employee remarked that he had had no idea that this coefficient was artificially high in order to promote electricity production: at the time, he said, he had thought that this coefficient expressed a law of nature.
26. Interview. See also Pierre Ailleret, "Les besoins d'énergie à long terme et l'énergie atomique," *Énergie Nucléaire*, vol. 4, No. 1, January–February 1962.
27. Interview.
28. Interview. Translation mine. Another interviewee confirmed this point, adding that the Ministry of Finance people would even get irritated at the high quality of EDF's economic studies.
29. Interviews.
30. Minutes of meetings of EDF's *Comité de l'Energie Nucléaire*, January 18, 1960 and September 23, 1960.
31. Interviews; Minutes of meetings of EDF's Comité de l'Energie Nucléaire, October 21, 1960.
32. Interview. Translation mine.
33. Interview. Translation mine.

34. Interviews; Picard, Beltran, and Bungener, *Histoire(s)*, op. cit.; Massé, *Aléas et Progrès*, op. cit.
35. Interview.
36. Minutes of the meeting of EDF's Comité de l'Energie Nucléaire, July 7, 1961. By "objective cost," they meant the price of constructing the reactors not counting the interest rate or the amortization period.
37. Minutes of the meeting of EDF's Comité de l'Energie Nucléaire, February 7, 1962. At the meeting of the Comité de l'Energie Nucléaire on May 4, 1961, the committee concluded that EDF4 "must approach competitiveness by taking advantage of everything that will appear as a possible improvement during the construction of EDF3. One could very well envisage a solution in which the unloading is only done [when the reactor] is stopped, as long as this is not too slow" [translation mine]. This shows that unloading while the reactor was operating was not as favorable to electricity production as many afterwards claimed that it was: through EDF4, EDF engineers seriously doubted the appropriateness of this solution, and there seems to be no question that left to their own devices, they would never have picked this solution. It eventually did become appropriate because industry and EDF had to spend so much time ensuring that it would, but this would not have happened if it hadn't been for the insistence of the CEA on this point.
38. Minutes of the meeting of EDF's Comité de l'Energie Nucléaire, June 6, 1961.
39. Minutes of the meeting of EDF's Comité de l'Energie Nucléaire, March 7, 1962.
40. Minutes of the meeting of EDF's Comité de l'Energie Nucléaire, September, 28, 1962.
41. That the engineers explicitly designed EDF4 to be competitive with conventional plants is evident in "Element combustible EDF 4: Réflexions à la suite de la réunion du 5 Mars 1963; Service d'Etudes Générales Nucléaires, "Les appareils de chargement et de déchargement du combustible," for the CEA–EDF meeting program of September 17, 1963; EDF, Direction Production et Transport (Service de la Production Thermique), "Centrale Nucléaire à une tranche de 500 MW, réacteur graphite-gaz, Estimation des Frais d'Exploitation," December 27, 1963.
42. Lamiral, *Chronique*, op. cit., p. 56.
43. Ibid., p. 57.
44. Minutes of the meeting of EDF's Comité de l'Energie Nucléaire, June 15, 1960 and July 8, 1960; at the second meeting, the Comité concluded that it had to "study as of now what would be the loss in energy value . . . that would ensue from unloading [slugs] after a short irradiation [period] as a function of the average flow of fuel slugs that one would use in this fashion" [translation mine].
45. Minutes of the meeting of EDF's Comité de l'Energie Nucléaire, September 28, 1962.
46. Minutes of the meeting of EDF's Comité de l'Energie Nucléaire, March 29, 1963. Also "Esquisse d'un programme CEA-EDF de réacteurs de puissance," June 5, 1963, for the meeting of September 17, 1963.
47. And this is highlighted in "L'Evolution des Relations CEA-EDF," October 23, 1964: this memo notes that the CEA derives its power from "its scientific competence, its size (23,000 people), its direct dependence on the Prime Minister, [and] its role in the military program" [translation mine].
48. These studies were conducted in 1963, although their results were only published in 1964. See, for example, Jacques Gaussens, "Faut-il fixer un prix du plutonium?," *Bulletin d'Informations Scientifiques et Techniques*, No. 81, June 1964; also Jean Andriot and Jacques Gaussens, *Economie et Perspectives de l'Energie Atomique* (Paris: Dunod, 1964).

49. Minutes of the meeting of EDF's Comité de l'Energie Nucléaire, March 12, 1964 [translation mine].
50. Christian Stoffaës, "La restructuration industrielle, 1945–1990," in Lévy-Leboyer and Casanova, *Entre l'Etat et le marché* op. cit.
51. McArthur and Scott, *Industrial Planning*, op. cit., p. 179.
52. Ibid., p. 53.
53. According to several members of the commission interviewed by Picard *et al.*, PEON's significance and influence was primarily rhetorical: the commission had too many members, affiliated with too many different institutions (EDF, CEA, several private companies) to actually be able to decide anything concrete about the future direction of nuclear power in France. So even though the various controversies over nuclear development were played out in the PEON meetings, and formal plans for future development did emerge from the meetings, in practice decisions were taken within the institutions represented on the committee. Even the formal plans, it seems, were drawn from proposals put forth by EDF and/or the CEA. (See, for example, "Esquisse d'un programme CEA-EDF de réacteurs de puissance," June 5, 1963, for the meeting of September 17, 1963 [CB63.5]; "Préparation du Vème Plan Equipement Nucléaire," June 12, 1964; annule et remplace la note du June 11, 1964.
54. See Lamiral, *Chronique*, op. cit., for EDF3's problems.
55. On the shift of power within EDF from the engineers who directed much of the utility's development from its creation to the mid-1960s to the "economists–managers" who gradually took over planning and decision making as of the mid-1960s, see Frost, *Alternating Currents*, op. cit.
56. "L'Evolution des relations CEA-EDF," October 23, 1964. Translation mine.
57. Robert Hirsch, Administrateur Général, Délégué du Gouvernement, à Monsieur le Directeur Général d'EDF. Letter dated December 16, 1964.
58. "Filière graphite-gaz, Problème de répartition des commandes," October 19, 1965.
59. Ibid.
60. EDF, REN2, "La Politique Industrielle d'EDF," November 25, 1965. Translation mine.
61. Ibid.
62. Ibid.
63. Ibid.
64. EDF, REN2, "Complément à la note sur la Politique Industrielle d'EDF," December, 27, 1965. Examples of other engineers defending their contracting policy include: EDF, REN1, "La Chaudière Nucléaire," December 6, 1965; Memo from Yves Cordelle to Service d'Etudes Générales Nucléaires, EDF, re: "Marché d'ensemble 'clé en main'," December 20, 1965; EDF, Direction de l'Equipement, "Politique Industrielle EDF pour la filière gaz graphite," January 6, 1966.
65. For example, in a meeting of the Commissions des Finances in December 1965, Olivier-Martin had to defend EDF against accusations that engineers always wanted to build new things, and did not in fact pay all that much attention to cost. Minutes of the December 16, 1965 meeting of the Commission des Finances on "Dépenses d'Investissements."
66. EDF, REN2, "Complément à la note sur la Politique Industrielle d'EDF," op. cit.
67. Frost, *Alternating Currents*, op. cit., and Picard, Beltran, and Bungener, *Histoire(s)*, op. cit.

68. EDF, "Filière Gaz Graphite, Lotissement des Commandes," December 12, 1965. EDF, Direction de l'Equipement, "Politique Industrielle EDF pour la filière gaz graphite," January 6, 1966.
69. "Note sur Politique Industrielle d'EDF en matière de Centrales Nucléaires," March 1, 1966; EDF, REN2, "Répartition des Commandes," January 21, 1966.
70. The Communist labor union. This union included the majority of syndicated EDF workers.
71. Tourgeron declaration, February 1966.
72. "Extrait du Compte-Rendu de la Réunion de Direction du 17 Février 1966."
73. "Politique industrielle EDF dans les centrales de la filière gaz graphite," accompanied by a note from Roux to Bienvenu dated March 1, 1966 indicating that this was a draft of a note to be presented on March 24, 1966; also "Projet de rapport général (Ve Plan: Commission des Industries de Transformation): II: Objectifs et méthodes de l'amélioration des structures."
74. For more on the *guerre des filières*, see Frost, *Alternating Currents*, op. cit., Picard, Beltran, and Bungener, *Histoire(s)*, op. cit., and Lamiral, *Chronique*, op. cit.
75. Hecht, *The Reactor in the Vineyard*, op. cit.
76. For the best examples of such studies, see Thomas P. Hughes, *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore, Md.: Johns Hopkins Univ. Press, 1983); also Donald MacKenzie, *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance* (Cambridge, Mass.: M.I.T. Press, 1990).
77. Nuclear technology was not the only field that took on such significance: another field was computer technology, and in this domain similar issues were also raised, particularly during the infamous "Affaire Bull" (see McArthur and Scott, *Industrial Planning*, op. cit.). It should be noted, though, that even the computer industry did not acquire the symbolic or economic prominence that the nuclear program did—perhaps in part because it did not have as blatant a military importance, and in part because it did not interact with the same variety of industries.