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Technopolitics in the Fifth Republic

As the strategic practice of designing or using technology to constitute, embody, or enact political goals, technopolitics is a distinctive form of political action. Its effectiveness, however, depends at least partially on the broader political framework. The success of the CEA's technopolitical regime in the 1950s was due in good measure to the ministerial instability of the Fourth Republic and its leaders' collective unwillingness to engage in more conventional forms of nuclear policy making. These conditions changed in 1958, when Charles de Gaulle returned as head of government after a twelve-year absence.

De Gaulle and his allies attached tremendous symbolic importance to French nuclear achievement. The ensuing centrality of the nuclear program to government politics had double-sided and somewhat ironic results for its developers. The program acquired greater importance, but the actions of nuclear leaders underwent greater scrutiny. Gaullists fully embraced the notion of technological radiance, which gave technologists greater visibility and respect. This in turn meant that technopolitics became a more important and powerful form of political action. It also meant, however, that technopolitics became more complex and contested. Conducting nuclear technopolitics now involved more than embedding preexisting political goals into technological artifacts. Increasingly, technologists had to shape their agendas and practices in ways that would be compatible with Gaullist discourse on national identity and industrial development. The technopolitical regimes of the CEA and EDF no longer had exclusive control over the terms in which debates about France's nuclear future were conducted.

In this chapter, in order to understand these changes, I return to the debates between the CEA and EDF over the development of the gas-graphite reactor program. Here I concentrate less on final reactor design and more on design practices, project organization, and program development. After surveying the design battles over the EDF2 and EDF3 reactors, I focus on three topics that arose repeatedly in battles between the two regimes from the mid 1950s to the mid 1960s: optimization techniques and the nuclear kilowatt-hour, the control and pricing of plutonium, and industrial competitiveness. Utility engineers began to include economic models and other optimization techniques into their design practices, not only because these forms of systems analysis facilitated reactor design but also because they were useful defensive strategies against attacks on EDF expertise. EDF later used those changed practices to negotiate with the CEA over plutonium production. Meanwhile, the issue of industrial competitiveness on foreign markets became increasingly important in national politics. This issue was a focus of debates between the two regimes over how to export reactors, which in turn led to conflicts over contracting, project organization, program development, and the national interest.

My analysis shows how engineers and other technologists used technopolitics not just to solve the problems at hand, but also to extend their influence beyond their regimes, articulating and enacting their vision of the nation. At the same time, I examine instances in which the technological foundations of these technopolitical activities shaped their political effectiveness or potential. Notably, I discuss the political implications of the cracking of EDF1's containment vessel, and of the fact that all gas-graphite reactors (even those designed to produce electricity) produced at least some plutonium as a by-product. These examples highlight the distinctiveness of technopolitics as a strategic practice and emphasize the importance of taking the physical attributes of technologies seriously even when discussing their political dimensions.

Before I return to the subject of the nuclear program, however, I must discuss the role of technological development in Gaullist discourse on national identity.

Technology and Gaullism

In 1958, the mounting colonial crisis in Algeria induced Charles de Gaulle to return as head of government. The following year marked the official beginning of the Fifth Republic. The new constitution gave the state a stronger role in directing the economy and rendered the executive branch of government less vulnerable to political upheaval. De Gaulle hoped that strong leadership would help him heal his nation from the hardships of reconstruction, the political turmoil of the Fourth Republic, and the rifts caused by the wars in Indochina and Algeria. Above and beyond all this, he wanted to restore France to its former glory. Among other things, this meant steering an independent course in the escalating Cold War—a course clearly separate from that of the communist Soviet Union and also from that of the United States. (De Gaulle saw the United States as economically and culturally imperialistic.) Technological development was central to this independence.

In making a case for French technological radiance, de Gaulle used language and images that strongly resembled those used by the technologists we encountered in chapter 1. At the end of the war, he had declared: "Vanquished today by mechanical force, we can vanquish tomorrow with a superior mechanical force."[1] Like the technologists and the planners, he associated France's political and economic weakness with scientific and technological backwardness. As Olivier Wieviorka has argued, de Gaulle believed that only intensive scientific research could solve this problem. One of his first acts as president was to promulgate a decree restructuring the organization of state-sponsored scientific research.[2] For de Gaulle, scientific research led directly to technological development. And he linked technological prowess to political status in no uncertain terms: "We are in the epoch of technology. A state does not count if it does not bring something to the world that contributes to the technological progress of the world."[3] Technological prowess could therefore serve as an important foundation for international diplomacy. Losing so many former colonies had seriously diminished France's worldwide radiance, but the nation could recuperate much of its lost prestige by offering technological assistance to developing nations. Indeed, doing so would help break the hegemony of the United States and the Soviet Union over the rest of the globe.[4]

Of course, for technologies to function effectively in these symbolic and diplomatic roles, they had to be French. Here too de Gaulle's rhetoric paralleled that of technologists. "Being the French people, we must reach the rank of a great industrial state or resign ourselves to decline. Our choice is made. Our development is in progress," he declared in 1960. But achieving a properly French course was somewhat trickier. According to Wieviorka, de Gaulle viewed technology as a double-edge sword: it had the power to wreak social and cultural havoc, but human choice could also turn it into a tremendously useful political, cultural, and economic tool. De Gaulle particularly feared the homogenizing power of widespread technological development. He wanted to ensure that France would remain unique. In a 1965 memo he asked his advisors: "In the scientific, technological, [and] economic competition in which the world is engaged, 1) by which means, in which areas, and to what extent is our national character threatened (in particular by the United States)? 2) in which directions (research, technology, economic sectors) should we direct our principal efforts in order to maintain, and, if possible, develop our national character?"[5] For de Gaulle, technology was ultimately malleable. A supremely French technology—one that would both express and develop French identity—constituted an obvious and attainable goal. Again, this goal meshed well with that of many technologists to develop a specifically French technological style. The Gaullist regime provided an ideal framework within which to pursue the technopolitics of national identity and radiance. The question was thus not whether to engage in technological *grands projets* but how to do so.

De Gaulle considered the nuclear program to be the jewel in France's technological crown. He attached special importance to the development of a nuclear *force de frappe* (strike force). He did not harbor the slightest doubts on this score. In 1963 he declared: "The question [in the 1950s] was . . . whether we ourselves would possess these means of dissuasion and these new ferments of economic activity, as we easily could, or if we would hand over to the Anglo-Saxons our chances of life and . . . death on the one hand, and . . . our industrial potential on the other. This question is settled."[6]

De Gaulle's return to power could not have come at a better time for the CEA's nationalist technopolitical regime. The agency as a whole was a favorite of the general's, in part because he had helped create it, and in part because it could fulfill his most cherished dreams of French radiance. The regime's principal mission officially became the production of a nuclear arsenal. No longer needed as a backstage negotiator, Pierre Guillaumat joined de Gaulle's ministerial cabinet in 1958 as Minister of the Army. Later he was a special advisor to the prime minister. It would have been difficult for any institution to have more government support. Not surprisingly, the CEA regime's persistently Gaullist, nationalist outlook would continue to attract important political backing throughout the 1960s.

For EDF's nationalized technopolitical regime, the advent of the Fifth Republic had more complex implications. Many engineers and managers continued to espouse the tenets of their regime, including the dominance of nationalized companies over private industry. But this tenet conflicted on several fronts with those of the government. The Gaullists favored a version of the "policy of champions." They sought to reduce

Table 3.1
French reactors of the 1950s and the 1960s. Values for power represent the maximum potential operating power of the reactors; these do not always correspond to original predictions or average yearly power production. Source: Lamiral 1988.

Reactor	Design type	Power (MW)	Project decided[a]	Ground broken	Operation started
G1 (CEA)	Gas-graphite	7	1952	1955	1956
G2 (CEA)	Gas-graphite	40	1955	1956	1959
G3 (CEA)	Gas-graphite	40	1955	1956	1960
EDF1	Gas-graphite	70	1956	1957	1963
EDF2	Gas-graphite	210	1957	1958	1965
EDF3	Gas-graphite	400	1959	1961	1966
Chooz A (Franco-Belgian project)	Light water	305	1960	1962	1967
Brennilis (CEA)	Heavy water	70	1961	1962	1967
Phenix (CEA)	Breeder	233	1961	1968	1973
EDF4 (later SL1)	Gas-graphite	460	1963	1963	1969
Bugey 1 (EDF)	Gas-graphite	540	1965	1965	1972
EDF5 (later SL2)	Gas-graphite	515	1966	1966	1971
Vandellos (built in Spain by EDF)	Gas-graphite	480	1966	1967	1972
Tihange (Franco-Belgian project)	Light water	870	1968	1969	1975

a. Year of decision to build.

domestic competition between companies and to help the strongest private companies become more powerful presences in international markets. Such ideas gained considerable ground over the course of the 1960s, not just in the private sector but also in the utility. Within EDF itself a new group of economist-managers rose to power, slowly in the 1950s and more rapidly in the 1960s.[7] These men sought to recast EDF's regime in a mold that would be more favorable to capitalist industry. They advocated a somewhat modified version of the "policy of champions" toward such ends. While they continued to promote the concept of nationalization, they had little use for that concept's social(ist) implications. Their rise led to intense debates over the meaning of nationalization, and to a political and professional split within the utility between economists and engineers.

One of these economist-managers was Pierre Massé, who had served as the utility's associate director general for more than ten years when he was named Plan commissioner in 1959. In the early years of his reign, de Gaulle repeatedly declared his faith in state planning. By appointing Massé, he sought to restore the significance and prestige of the Plan, the influence of which had waned considerably by the end of the Fourth Republic. Under Massé, its mission shifted from reconstruction and modernization to broad social, economic, and industrial development.[8] Massé's appointment gave EDF's remaining economist-managers a powerful ally within the state. He promoted at a national level the design practices and industrial policies they pursued at the institutional level, thereby supporting and legitimating shifts in the utility's technopolitical regime. EDF nuclear engineers changed their language and techniques to accommodate these shifts, but in the process they lost a great deal of their influence over programmatic issues.

How did the technologies of the program (including artifacts, practices, and forms of organization) come to constitute technopolitics? And how did these technopolitics reflect and shape broader debates about France's identity and future? Between 1955 and 1969, EDF and the CEA collaborated in designing five more gas-graphite reactors (table 3.1). Tracing the shifting terms of debates throughout this collaboration will help me address these questions.

Technopolitics from the Fourth to the Fifth Republic: EDF2 and EDF3

For better or worse, the EDF and CEA regimes had to continue collaborating on the gas-graphite program. The EDF1 project established a rocky but manageable working relationship. As the foundations for this reactor were being laid at Chinon, engineers began contemplating the next two reactors destined for the same site. Once again, the differences in the two technopolitical regimes manifested themselves. This time, the central object of dispute was reactor power. Engineers imbued the number of megawatts that future reactors would produce with a variety of political and industrial meanings.

Engineers at EDF's Direction de l'Equipement (the division in charge of plant design and construction) continued to concentrate on producing as much electricity as possible. They therefore focused on *rendement* (output). From this perspective, it made sense to make EDF2 more powerful than its predecessor. The utility's strategy for developing conventional power—which involved increasing the output of successive plants—supported this tactic. Furthermore, EDF engineers saw themselves as competing with their British counterparts, who also pursued this strategy in nuclear development. Operating in a technopolitical regime directed at producing energy, Equipement engineers measured technological prowess by power output. Industrial habit, national competition, and institutional pride all clearly indicated, therefore, that France should steadily increase the power of its reactors. In a design hastily drafted in September 1956, EDF engineers proposed a 100-megawatt reactor that would use 150 tons of uranium encased in a spherical metal pressure vessel and cooled by carbon dioxide flowing through the core at a pressure of 35 kilograms per square centimeter.[9] They presented these parameters to their CEA counterparts for review.

Though CEA engineers conceded that EDF reactors had to produce electricity, they also wanted more plutonium. This goal remained tacit—though not exactly secret—until the French bomb was announced; thereafter it became quite explicit. The CEA engineers hoped to design a reactor that would fulfill both purposes simultaneously.[10] To this end, they revised EDF's proposal by adding more than 100 tons of uranium to the core and halving the pressure of the cooling gas. The revised design would produce 14 percent more electricity than the original one, using nearly 70 percent more fuel.[11] The extra uranium, presumably, would be converted into plutonium.

This new design contradicted the very essence of what EDF's regime held up as good engineering practice: the idea of *not* trying to extract as much energy as possible out of fuel seemed scandalous. If the CEA could actually supply over 100 extra tons of uranium, EDF should get more than a meager 14 extra megawatts in return. Furthermore, since drafting their preliminary design, utility engineers had held several discussions with their British counterparts. The British had developed a fuel rod for their gas-graphite reactors that could stay in the reactor longer, producing more energy and leading to even greater fuel efficiency. Upon hearing this news, EDF engineers thought that the French should at least match (if not exceed) the British in this domain, and hoped that their CEA colleagues could design an equally impressive fuel rod. Working furiously to devise a counter-proposal before the next meeting with the CEA, EDF engineers triumphantly produced a new reactor project. This version would use only 2 tons more uranium than the CEA had proposed, yet it could produce 167 MW of electricity. This performance, however, was predicated on the CEA's ability to design a fuel rod similar to the British one.[12]

CEA designers disliked this counter-proposal for several reasons. They too wanted to match or outdo the British, but their regime had a different criterion for prowess: reliability, not power. Britain had just experienced a serious accident at its Windscale reactor, so the French would outdo the British even if they simply managed to build a power reactor that ran without failure. CEA engineers feared that the much larger reactor proposed by EDF would increase the chance of problems in construction and operation. They especially feared that they might have difficulties designing the fuel rods posited by EDF. If their fuel rods were inadequate, the reactor would have to be stopped frequently for reloading. This, in turn, would result in a drop in availability, which would certainly undermine the image of France's nuclear program, and for which CEA engineers did not want the blame.[13] Most of all, though, a more powerful reactor would make extracting weapons-grade plutonium from the reactor's spent fuel extremely difficult, since running a reactor at higher power meant that the plutonium produced by the uranium fissioning inside the core would itself turn into other, non-weapons-grade isotopes.[14]

Debates between the two groups of engineers continued for several months as they countered each other's proposals and attempted to reach a compromise. The EDF team kept pushing the power threshold higher, while the CEA team grew more explicit and forceful in demanding plutonium. The final design, settled in April 1958, represented both a technical and a rhetorical compromise between the two institutions. The reactor core, encased in a spherical metal pressure vessel, would contain 251 tons of uranium, cooled by CO_2 at a pressure of 27 kg/cm^2. The reactor would run two alternators of 125 MW each, but instead of publicizing all 250 MW, designers would bill EDF2 as a 175-MW reactor. Hence, EDF could get the prestige of running a powerful reactor and retain the option of eventually extracting even more power from it. The CEA, meanwhile, had more leeway in designing new fuel rods. And, as later became clear, since EDF had only committed itself to extracting 175 MW from EDF2, the CEA would have an easier time getting some plutonium out of it. Thus, EDF2's design features were inextricably bound to the politics of national prestige and of industrial and military production. As a hybrid not only of technology and politics, but also of two technopolitical regimes, EDF2 itself would become part of the technopolitics of ensuing battles over the program's future.

The compromise achieved with EDF2 had in no way tempered the goals of either team. Disagreements resumed during the CEA-EDF meeting held in May to discuss the next reactor. The EDF team wanted to

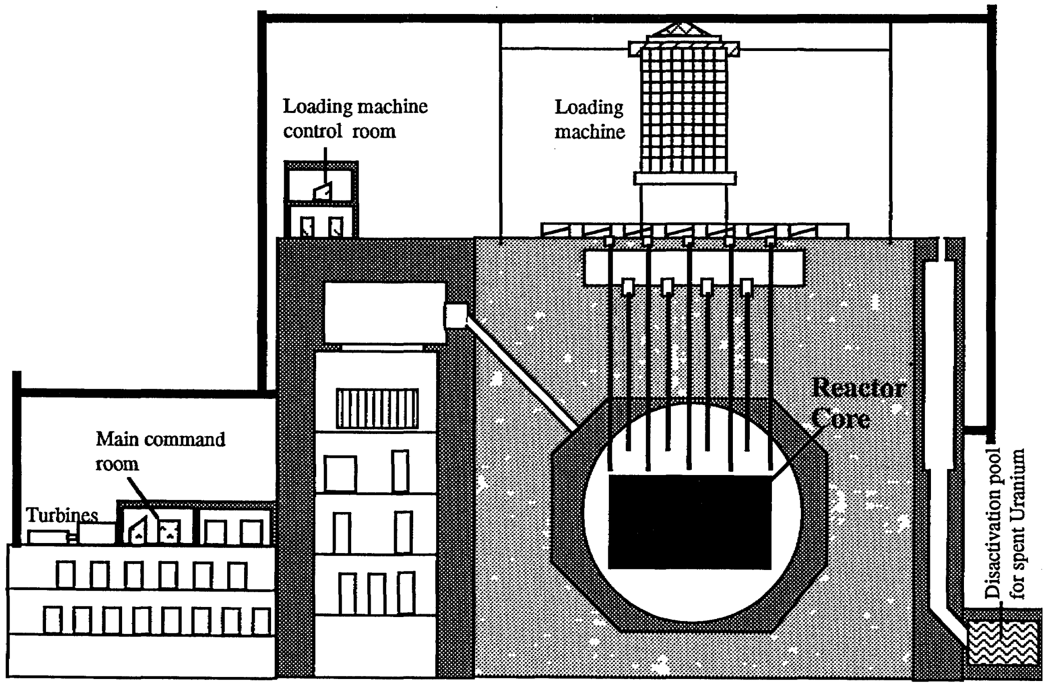

Figure 3.1
A schematic diagram of EDF2 (not to scale). Source: C. Bienvenu et al., "Les centrales nucléaires EDF 2, EDF3, EDF4," Conférence de Genève, 1964. Drawing by Jay Slagle.

make another big power leap with EDF3 by using two 250-MW alternators (the latest innovation in conventional power production) to run the reactor at 500 MW. Raising the same objections as they had in the previous round, CEA designers resisted and argued that a 250-MW reactor would suffice.[15] EDF engineers countered that if EDF3 ran at 500 MW it would be the world's most powerful reactor—a highly significant national achievement that would fit well within the CEA's regime. Once again, invoking the nation proved compelling. The CEA offered a compromise at 375 MW: this way, EDF3 would still achieve the distinction of being the most powerful of reactors, but instead of two new alternators it would use three of the more tried and true 125-MW alternators.

A technological mishap introduced a new hurdle into the discussions before anyone could settle the matter, however. Early one morning in February 1959, an explosion ripped through the Chinon site as a huge crack suddenly appeared in EDF1's spherical steel containment vessel, which builders had almost finished welding together. The cause of the problem—inadequate thermal treatment—soon became clear.[16] The solution, however, eluded both the private company building the containment structure (Levivier) and EDF. Of course, the incident also greatly

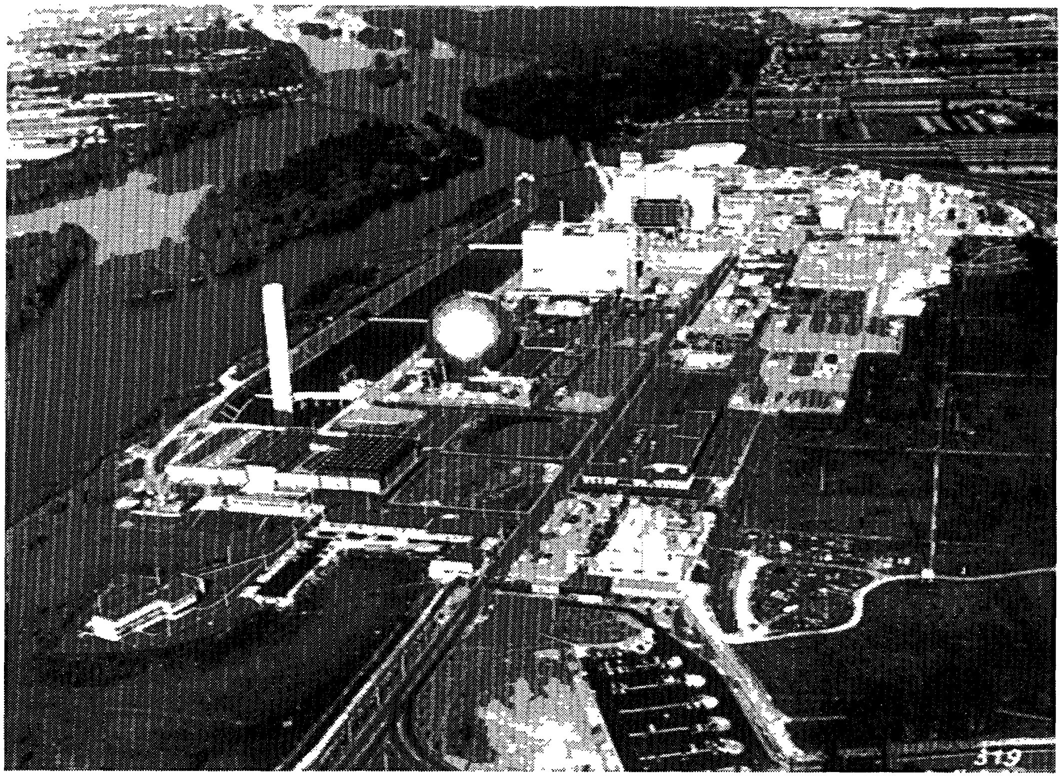

Figure 3.2
An aerial view of the Chinon site in 1966. EDF1 (the sphere), EDF2, and EDF 3 are lined up along the bank of the Loire. This image and others like it were used in EDF's annual reports, in brochures for the Chinon site, and on postcards sold in the region. Source: EDF Photothèque.

embarrassed both outfits. It received extensive press coverage (in which much was made of the fact that the accident had occurred on Friday the thirteenth), and for several weeks EDF and Levivier were the laughing-stock of the CEA.[17]

The Chinon incident soon became technopolitical ammunition for the CEA and others to use against EDF. Some engineers at the CEA immediately blamed the crack on EDF's stubbornness in choosing to build the containment vessel out of steel rather than prestressed concrete. Indeed, the material of the vessel had been another bone of contention during EDF1 negotiations: the CEA (promoting, as usual, its "policy of champions") had argued that using prestressed concrete would enable French industry to develop its strength in that area, and EDF had countered that steel was cheaper and better. Not only was the vessel material already part of the technopolitics pursued by both institutions; the incident also enabled the CEA to reopen the issue of industrial contracting. The problem would have never occurred, some argued, had the utility not insisted on being its own general contractor rather than appointing a private company for that job.[18]

Perhaps most significantly, however, the accident shifted debates about nuclear technology into a more public arena. EDF as a whole had faced plenty of public criticism since its creation, but this was the first real mishap that the *nuclear* program had encountered.[19] Significantly, it represented the first time that the state criticized the nuclear branch of EDF's technopolitical regime. Planning commissioner Pierre Massé questioned the judgment of this regime and suggested that it rethink its relationship with private industry. Massé and several private industrialists told the Direction de l'Equipement that they did not like the idea of building increasingly powerful reactors, as engineers proposed to do with EDF2 and EDF3. Better, they said, to follow the CEA's advice and build a larger number of small reactors. Their reasons, however, did not emphasize reliability (the criterion proposed by the CEA's regime) so much as the need to give private companies more experience in the nuclear sector—again, in the interest of the nation (specifically, its economy).[20] In effect, Massé and the private companies proposed a revision of EDF's technopolitical regime away from a leftist version of nationalization. EDF's nuclear engineers[21] mistrusted this proposal, suspecting private industry of trying to seize technical terrain and make commercial gains without regard for the long-term future of the nation and its technological development.[22] Capitalism, in other words, was trying to overrule nationalized industry so that it could profit at the expense of the public and the national good.

The EDF1 incident reveals another aspect of the mechanisms of technopolitics. A technological event—a crack in a steel containment vessel—became a tool in a broader debate over industrial policy. This could happen precisely because the technology already had multiple political meanings. Had this not been the case, the failure of an EDF1 component would not have made good technopolitics. Under the circumstances, however, the cracked vessel provided an event that served to make and justify a critique of EDF's technopolitical regime. The undeniable materiality of the event dramatically strengthened this critique. Previous arguments for or against this regime had rested almost entirely on ideology and theory. The crack provided material evidence—which carried superior weight in both regimes. EDF's nuclear engineers could not ignore this critique. Nor could they deal with it effectively simply by pointing once again to their special sense of public responsibility as state engineers and members of a nationalized institution. They too would need other evidence to defend themselves.

Optimization and the Competitive Kilowatt-Hour

To defend their technopolitical regime and the France it sought to produce, EDF nuclear engineers introduced modeling techniques into their design practices. At first they used economic studies and models mainly as rhetoric, to justify decisions they had already made. As they became more proficient with economic analysis, however, its techniques began to permeate their decision-making processes. Soon they began to use models that incorporated both technical and economic data not only to justify but also to make choices about reactor design and program development. What started as a rhetorical defense weapon ended up as an integral part of EDF's nuclear technopolitical regime. Throughout the 1960s, it enabled this regime not only to make and defend choices, but also to reshape the terms of the nuclear debate.

As we saw in chapter 1, these modeling techniques derived their technopolitical credibility and visibility from their role in developing the fourth and fifth plans. Their origins in France, however, lay within EDF itself. According to his own account, Pierre Massé was largely responsible for combining the techniques of econometrics[23] and systems analysis[24] and introducing them to the French industrial world. As EDF's Associate Director General, he had elaborated economic optimization models and employed systems analysis to help design EDF's distribution network and regulate its overall system of energy production.[25] Massé's models had won the respect of engineers and managers throughout the utility, and recognition in private industry as well as abroad. When he moved from EDF to the Plan, he left a solid legacy of systems analysis and economic modeling behind, mainly concentrated in a division specially devoted to studying the economics of energy supply: the Service des Etudes Economiques Générales (SEEG), run by the brilliant young economist Marcel Boiteux.[26] The SEEG's main tasks were to forecast the nation's electricity demand, to analyze external factors that would influence the cost and pricing of electricity production, and to prepare management and rationalization tools to help "optimize" the electricity production and distribution system.[27] Initially, most of 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, "the important thing is to convince."[28] With Massé directing the Plan, the SEEG certainly provided EDF with the tools it needed to persuade the government to support its development programs.

By the early 1960s, systems analysis and economic modeling were well established as powerful means of technopolitical persuasion. With the rising prestige of the Plan, the mode of reasoning represented by these techniques gained more and more respect and credibility throughout French industry. Its power derived from several synchronous and related developments: the increased prestige of numerical analysis, the growth and mathematization of economics, the ability of models to provide apparently objective solutions to otherwise unmanageable problems, and the increasing numbers of econometrically trained men in state institutions.[29] At least one of the high-level managers in charge of nuclear affairs at EDF—Pierre Ailleret—had intimate knowledge of these techniques. In the 1950s he convinced the SEEG to change how it predicted the growth of energy demand. Uses for electric power were developing so rapidly, he argued, that consumption would increase geometrically rather than linearly. He predicted that it would double every ten years, and what started out as a simple forecast became, in Ailleret's own word, a "doctrine"—a basis for demand forecast and therefore for programmatic development.[30]

Ailleret differed from Massé in his opinion of the nuclear program. Massé had a lukewarm attitude toward nuclear energy in the 1950s and the 1960s: he thought it had a future, but a distant one, and he doubted the wisdom of pursuing the gas-graphite line (or so he claimed retrospectively).[31] Ailleret, as we have seen, had nothing but enthusiasm for nuclear technology—so much so that nuclear reactors were originally known at EDF as "Ailleret's playthings."[32] Recall that he had persuaded the CEA to include "energy recuperation installations" in the Marcoule reactors. He had been closely involved in EDF's nuclear activities ever since, most notably heading the utility's Nuclear Energy Committee, where the top nuclear engineers and managers made design and development decisions. He therefore had a tremendous stake in the success of EDF's gas-graphite reactors.

When EDF's nuclear regime began to face serious criticism after the Chinon mishap, Ailleret suggested conducting a few simple "economic studies" to compare the capital costs (i.e., the amount of investment required) of a second reactor based on EDF1 with those of EDF2's proposed design—in other words, to compare the policy advocated by the CEA, private industry, and the Plan with that advocated by EDF's nuclear team. Regardless of the results, Ailleret said, "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]."[33] Completed a few months later, the study showed that the capital costs of EDF2 (30 billion francs) were less than twice those of EDF1 (16 billion francs). Considering that EDF2 would produce nearly three times as much electricity, Ailleret and his nuclear engineers concluded that copying the first reactor hardly seemed worthwhile.[34] EDF2 went ahead as planned.

The favorable outcome of this study encouraged the Nuclear Energy Committee members. They promptly launched a more sophisticated study aimed at settling the EDF3 quarrel. This study analyzed the costs of both proposed designs. To carry this out, EDF asked private companies to bid on both designs. Incorporating these bids into the models showed the CEA and the Planning Commission that EDF's solution, a reactor with two 250-MW alternators, was cheaper. Utility engineers marshaled additional arguments to bolster their position. A smaller reactor would still not reach the "industrial stage," and the more reactors they had to build to get there, the more money they would have to spend on research and development. Furthermore, nuclear agencies outside France had begun to treat 500 MW as the appropriate power threshold for gas-graphite reactors. The British had just announced that they would build a plant of that size, and the International Atomic Energy Agency in Vienna was using a 500-MW reactor as the gas-graphite prototype in its cost analysis of different reactor types. Clearly, 500 MW was the goal to shoot for, and the sooner EDF got there, the better for the French nuclear program and the nation. In the end, the two institutions reached a compromise: they would adopt EDF's technical solution, but they would announce a figure of 375 MW. This would give the CEA a sufficient margin of error (both technically, in terms of designing the appropriate fuel rod, and politically, in terms of not losing face for France should its engineers fail in this endeavor). At the same time, it would give EDF the experience of building a sufficiently large reactor.[35] Meanwhile, EDF engineers assured one another in a closed meeting that they would later do everything possible to try to run the new reactor at its full power capacity of 500 MW.[36]

This study of EDF3's cost greatly aided the utility's nuclear team to obtain its desired design. The analysis was still fairly rudimentary, though, providing only the roughest estimate of the costs of the reactor's largest components. Its main value to engineers lay in its rhetorical powers of persuasion. Yet together with the EDF2 study, it also had another effect: that of introducing nuclear engineers to the general ideas behind systems

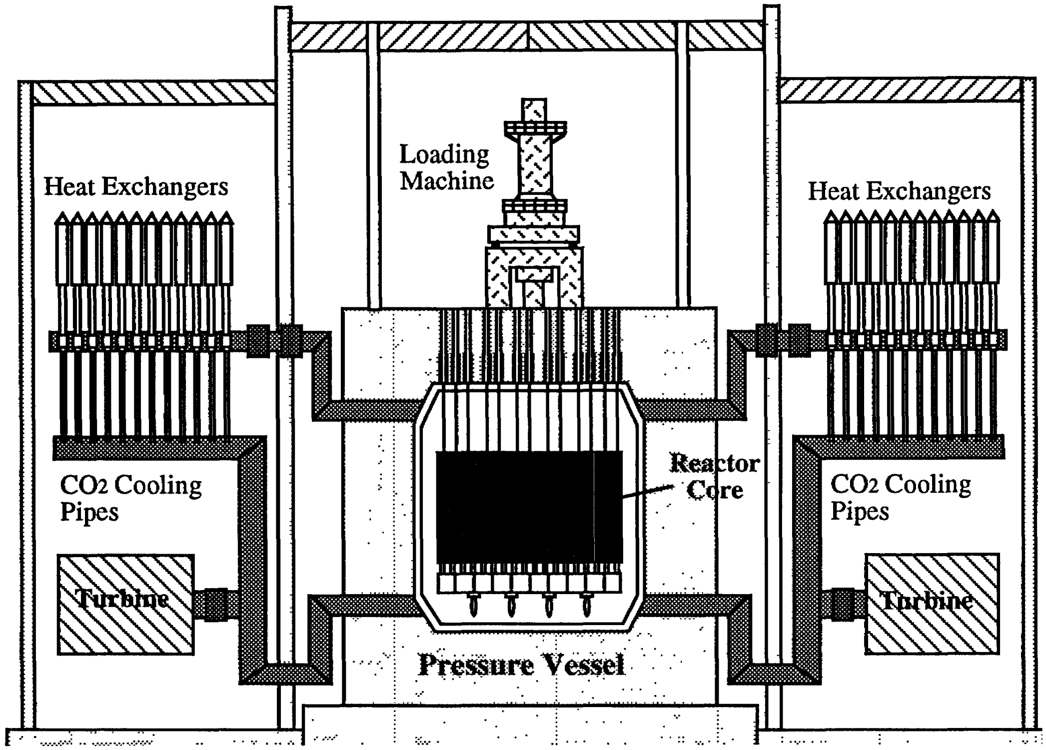

Figure 3.3
A schematic diagram of EDF3 (not to scale). Source: C. Bienvenu et al., "Les centrales nucléaires EDF 2, EDF3, EDF4," Conférence de Genève, 1964. Drawing by Jay Slagle.

analysis. In fact, one kind of systems analysis, known to the utility as "optimization studies," had been used for several years elsewhere at EDF in designing conventional power plants. These studies (which were somewhat more sophisticated than the one engineers had run for EDF3) broke down the cost of a power plant into the cost of its individual components. They then minimized the overall cost, either by finding ways to lower the costs of specific components or by redesigning certain components so that the whole plant would produce more power. They thus helped engineers find an "optimum" relationship between a plant's cost and its power output. These methods were not applied to reactor design until 1960, in part because so many variables were involved in reactor design that calculations were extremely difficult to perform with mere adding machines. The arrival of computers in EDF's research facilities changed this state of affairs.[37]

Indeed, just when the use of more complex forms of systems analysis became politically popular through Massé's Plan, computers made it possible for engineers to conduct optimization studies for their reactors.

Figure 3.4
Workers building the graphite pile for EDF3. The graphite casings are stacked on top of one another. The fuel rods will go in the casing holes. Photograph: Michel Brigaud, 1965. Source: EDF Photothèque.

Running the studies led to substantial changes in the design practices of EDF's nuclear engineers. Years later, one engineer described the design process before and after the use of optimization. Before, he said, "the whole trick . . . was to find the best compromise possible, without much economic data. . . . It was a mixture of common sense [and] intuition." Computers and optimization studies changed everything. "Until then these calculations had been done by hand. I'd had a young woman engineer with me [who ran most of these numbers]. . . . 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. . . ."[38] This increased sophistication meant that engineers could plug different design options into models in order to test which option would best suit their purposes.[39]

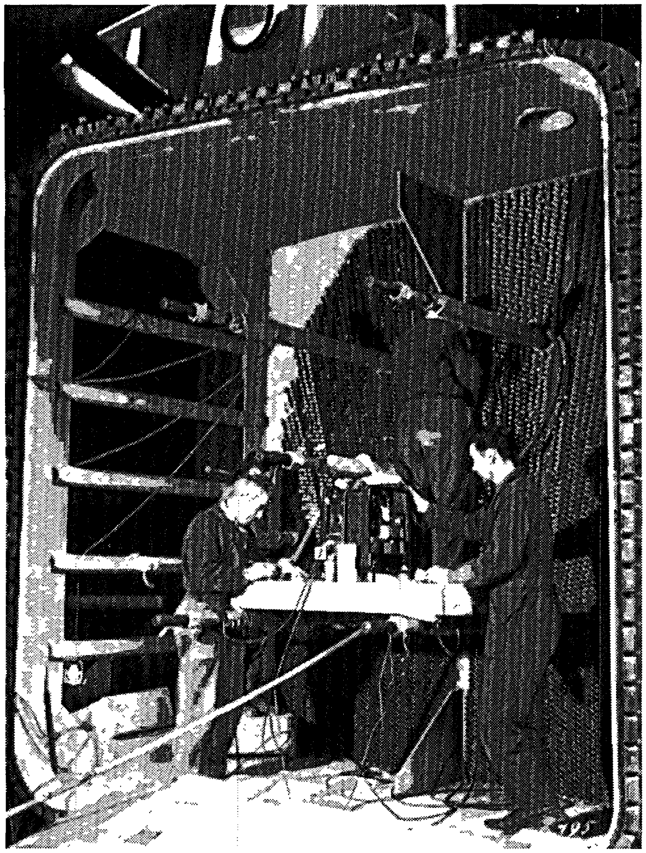

Figure 3.5
Workers hooking up part of the cooling system for EDF3. Photograph: H. Baranger, 1964. Source: EDF Photothèque.

The first optimization study done for reactors covered the design of EDF3. Its guiding principle was simultaneously technological and economic: to maximize the reactor's power while minimizing the volume of its core. This reflected the design traditions of utility engineers as well as their interest in getting as much energy as possible out of their fuel. Using reference costs provided by the SEEG and relationships among various core dimensions, engineers tried out different core configurations to calculate how to derive the most power from the least uranium. They could hence "prove" their assertion that increasing the unit power of a nuclear plant decreased the overall price per kilowatt of electricity.[40] Such proof greatly weakened the arguments of private industry and the CEA in favor of smaller reactors.[41]

Optimization studies thus refined how EDF engineers conducted their technopolitics. What started as a rhetorical device had now become an integral part of design practice. The means helped justify the ends. This

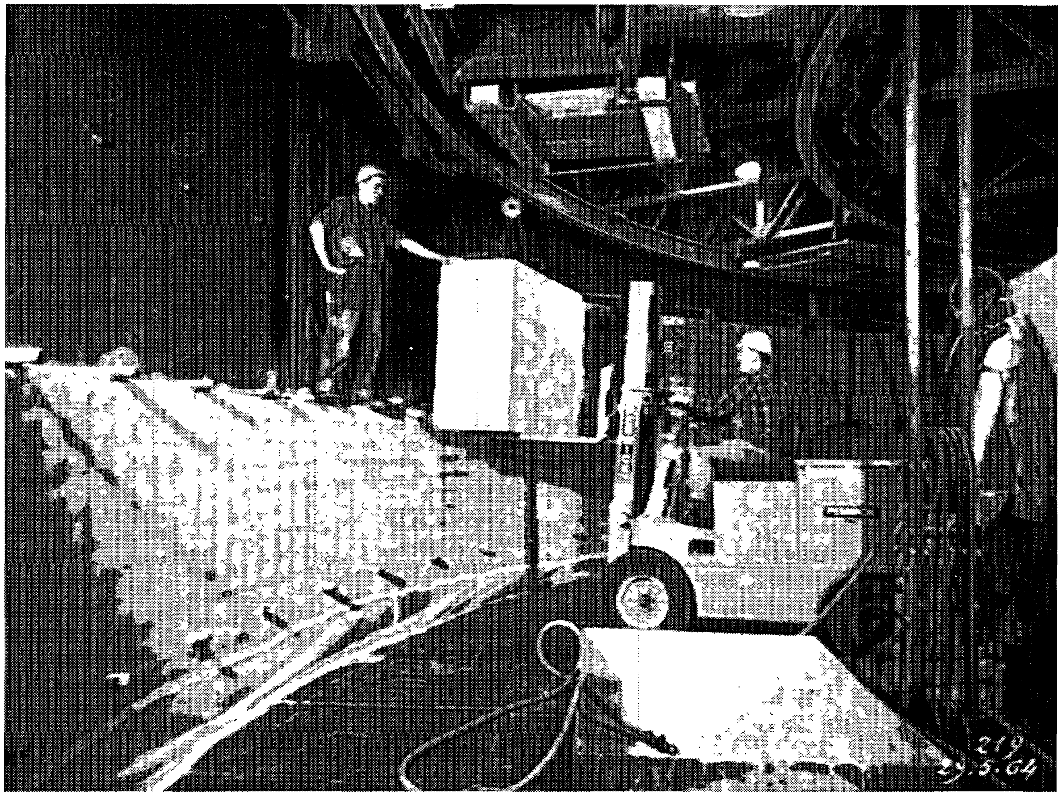

Figure 3.6
Workers mounting the concrete blocks for EDF3's pressure vessel. Photograph: H. Baranger, 1964. Source: EDF Photothèque.

shift helped EDF engineers present a reactor design optimized to fulfill their own goals as *the* optimal design, with those goals safely buried in the model. Nothing in the *models* prevented them from being used to optimize reactors for maximum plutonium yield or any number of other possible criteria. But the CEA did not seize upon these models. Thus, only EDF designs carried the prestigious label "optimum." Robert Frost and others have described the battles fought by EDF economists beginning in the 1950s to make their pricing schemes politically acceptable and the role played by the notion and techniques of the "optimum" in those battles.[42] By the early 1960s, those battles had been won, and the idea of the "optimum" had emerged victorious. Indeed, it had acquired an almost magical aura, again helped by Pierre Massé's position in the Plan. Even the finance ministry had been persuaded by the power of EDF's models: 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 studies. It is important to underscore this point, as [these studies] were very much appreciated by [the Ministry of] Finance. . . ."[43]

Everyone agreed that "optimal" technologies outranked others—and the only way to get an optimal technology was to run a model.

In one sense, these models functioned as microcosmic laboratories. They provided a way of testing different reactor designs without having to go through the extreme expense and effort of building them. Bruno Latour has argued that laboratories give scientists a resource that politicians can never have: the ability to make mistakes without suffering public humiliation. It is precisely in this specificity of science, Latour notes, that its power lies.[44] A similar argument holds for these optimization models. In the early 1960s, there were no hard operational data about the economics of nuclear power—sizable nuclear power plants had only just begun to come on line elsewhere in the world. Statements about the relative economic merits of different designs were, at best, educated speculations. The models, however, provided a widely respected method of "experimentation." By constructing different scenarios and extrapolating data, the models gave these speculations technical heft. They made calculations on paper acceptable substitutes for industrial experience. In the absence of operational data, then, the models gave EDF engineers a way to demonstrate the superiority of their designs: by transforming judgment calls into matters of fact,[45] they constituted an ideal means of technopolitics.

Learning the language and techniques of optimization helped utility engineers navigate the changing waters of the early 1960s. As the nation's priorities shifted from reconstruction and maximum production to economic efficiency and market-oriented production, EDF's overarching mission shifted from *rendement* (producing as much electricity as possible) to *rentabilité* (producing the cheapest possible electricity).[46] For nuclear engineers, this meant that the cost of the kilowatt-hour (i.e., the unit cost of the electricity actually generated by a plant in real time once it goes on line) became more important. Correspondingly, the cost of the kilowatt (i.e., the total capital cost of building the plant divided by the maximum number of kilowatts it can produce at any given time) diminished in importance. Increasingly, the power of a plant or how much it cost to build mattered less than the price of the electricity it produced, which combined these two quantities with others. This posed a problem, because none of EDF's reactors had actually begun to produce electricity (the first one, EDF1, wouldn't do so until 1963). At best, engineers could offer predictions.

Optimization studies offered a solution by helping EDF engineers turn the calculation of the nuclear kilowatt-hour into a "doable" problem. In the process, however, the EDF engineers had to reshape their technopolitical goals. Instead of aiming at a physical definition of efficiency (producing the maximum power in the most thermodynamically efficient manner), they began to search for a more economic concept of efficiency.[47] Optimization studies could not, of course, yield the actual cost of producing a nuclear kilowatt-hour. They did, however, give engineers a pseudo-experimental technique that enabled them to credibly predict that cost for different design options. Through this process, EDF engineers developed a new technopolitical goal: producing nuclear electricity that would compete economically with conventional power. Very quickly, comparisons between the two forms of power began to dominate their work. One participant said: “We lived in economic comparisons, in comparisons of the cost of the kilowatt-hour.”[48]

Comparing nuclear power with conventional power by means of optimization studies gave nuclear engineers new ways of both discussing and practicing their work. The change became evident in 1961 as they began to contemplate EDF4. Until then, they had aimed to make each plant more powerful than its predecessor. With EDF4, however, they decided to stay at the same power level. Not only was 500 MW an internationally accepted threshold for gas-graphite reactors (which allayed fears of lagging behind other countries); in addition, the engineers' priorities had changed. Now they would try to make the reactor “competitive.”[49] They saw two possible routes to this goal: either they could copy EDF3, improving each component as much as possible without changing the general parameters, or they could produce a radically different design that would place the heat exchangers inside the pressure vessel, underneath the reactor core. In June 1961 they expected their choice to depend not only on the price of each design but also on the future of the energy market. They did not expect copying EDF3 to save much money in the long run, but they felt it would provide an easier and faster short-term solution should an oil shortage develop in the next few years. If, however, prospectors discovered a significant reservoir of oil or natural gas in the Sahara, then the second option, which they expected to yield considerable cost savings in the long run, would be a better solution.[50] Aiming to compete with conventional power plants thus added the art of prediction to the art of designing a nuclear plant and drew on the forecasting techniques of the Plan. And the price of conventional fuel and power was not all that required forecasting. Designers also had to include predictions for fluctuations in interest rates and amortization periods. How long could they expect their reactors to produce electricity? Some predicted 20 years, others 35, but no one really knew. The most important thing, given these uncertainties, was to devise a credible, persuasive model. Showing that new reactors would compete economically with conventional power plants would go a long way toward acquiring political support for those reactors.

Optimization studies thus made technopolitics more complex by inextricably linking the goals and the practices of EDF's nuclear engineers. Having proved themselves politically efficacious in attaining predefined goals, these models also provided the impetus and means for engineers to reshape their goals.[51] The models did not invent the entity of the "competitive nuclear kilowatt-hour"; however, they made its existence possible by enabling engineers to produce the number that would define that entity. The existence of this entity, in turn, helped EDF's nuclear engineers garner political support outside the utility. No one—not the Plan, not the CEA, not even de Gaulle—would deny that a competitive French nuclear kilowatt-hour constituted a desirable goal.

Optimization technopolitics also served EDF engineers in the ongoing quarrels between EDF and the CEA over fuel and plutonium production. De Gaulle's inexorable pursuit of the military atom helped the CEA to impose its plutonium requests on EDF. But EDF's design practices, politically supported as they were by the priorities and interests of the Plan and the Ministry of Finance, and entwined as they were with the goal of "competitive" nuclear power, enabled the utility to shift the terms of debates about reactor fuel and plutonium from production to cost.

Controlling Fuel and Pricing Plutonium

"So I hear you've been asking about plutonium," said one CEA engineer as we shook hands at our first meeting. "You know, EDF made some plutonium too." I was too stunned to reply at first. Then I smiled weakly and assured him that I wanted to hear all about it. I sat down and tried to calm myself as I set up the tape recorder. What had shocked me was not the revelation about EDF plutonium. This was something that every gas-graphite engineer knew, and treated either as a dirty public secret ("This may surprise you, mademoiselle, but they made plutonium at Chinon too") or as a completely uninteresting fact ("Oh yes, sure, the Chinon reactors made some plutonium—but that was technologically inevitable, you know"). What had shocked me was the fact that my interview subjects had evidently been talking about me and my questions. Clearly they were watching me as closely as I was questioning them.

Reactor fuel had always been a source of contention between EDF and the CEA. In the early to mid 1960s, as questions that had plagued the relationship between the two institutions became increasingly important, it was one of the main foci of dispute. Who would control the fuel at which point in the cycle? Would the CEA be willing and able to design fuel rods that would perform according to EDF's wishes? How much fuel would each reactor use? CEA technologists strongly felt that their institution had "exclusive responsibility" for providing fuel for all French nuclear plants. The director of the CEA's fuel division put this in no uncertain terms:

> There is no question of . . . establishing a [fuel] supply program in common. It is only a matter of noting the size of the order by type of fuel [rod]; it is the CEA's business to deal with the rest. . . . We have noticed that [EDF] would be ready to claim that it can ensure its [fuel] supply itself. I think that it would be most unfortunate if this inclination were to develop further, because it would remove one of the CEA's primary responsibilities and means of action in this joint effort.[52]

Controlling the fuel cycle, in other words, constituted the most important means by which the CEA's regime participated in the development of nuclear power. Relinquishing technical control over any part of that cycle would also mean relinquishing political influence within the program.

How much fuel would go exclusively toward electricity production, and how much would the CEA remove from the reactors for treatment at Marcoule's plutonium facility? This question caused the most acrimony between engineers in the two regimes: every demand made by the CEA for plutonium from EDF reactors felt like an invasion to EDF engineers, while every resistance on the part of the latter felt like a betrayal to the CEA engineers. Matters were not helped by personality clashes: the heads of EDF's engineering teams, including Claude Bienvenu and Boris Saitcesvsky (who had been involved in EDF's reactor projects from the earliest days at Marcoule), could not abide Jules Horowitz, the *polytechnicien* head of the CEA's Direction des Piles Atomiques. The feeling was entirely mutual.

Though EDF reactors were optimized for producing electricity, the fission reaction in their cores would inevitably yield some plutonium as a by-product: such was the nature of natural uranium reactors. This technological fact opened up a political possibility for CEA engineers. Perhaps they could persuade EDF to remove some fuel rods before they were fully exhausted (by the standards of power production) in order to extract weapons-grade plutonium? EDF engineers were neither surprised nor thrilled when, in 1960, their CEA colleagues made the first official request to this effect.[53] They would have liked to refuse the request, but de Gaulle's enthusiasm for the *force de frappe* made that impossible. It was now the CEA's turn to invoke the nation: refusing to supply plutonium would have been positively unpatriotic. After extensive discussions with the Ministry of the Armies, the Ministry of Atomic and Space Affairs, the Ministry of Industry, and the CEA, EDF gave in.[54] Once again the technological versatility of the gas-graphite design had served the CEA's regime well. But this agreement of principle did not dictate the *terms* of EDF's cooperation. In negotiating these terms, EDF's nuclear engineers used their newly developed practices and goals to redefine the economic and political implications of plutonium production.

As of February 1961, the official arrangement was that (barring an unforeseen problem at the Marcoule reactors) no more than one-sixth of Chinon's fuel would go toward producing military plutonium, and this only as of 1966. Two months later, CEA engineers asked for more: they wanted to use one-fourth of Chinon's fuel capacity. Both EDF and its protectors at the Ministry of Industry protested vigorously, arguing that this quantity would seriously impair EDF's ability to derive adequate operational experience from its own reactors. Already, EDF's Nuclear Energy Committee had begun thinking about various forms of compensation. One option involved calculating how much energy would be lost by removing fuel rods before full irradiation and pricing that energy on the basis of the cost of producing the equivalent amount in a coal plant.[55] This kind of formula seemed straightforward enough, and the CEA had been willing from the beginning to contemplate financial compensation in the form of a rather vaguely conceived and ill-defined "plutonium credit."[56] In April 1962, the two institutions redrew their agreement. The CEA would give EDF a set number of specially designed fuel rods 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 set a limit on how many rods of each type would go into the reactors; and both institutions would evaluate the "inconveniences" caused in the operation of the reactors by plutonium production and establish compensatory measures.[57]

These measures remained undefined, however, and the escalation in the dispute became almost humorous as each engineering team thought of more and more factors that simply *had* to enter the calculations. Soon after the second agreement, for example, the CEA resurrected the possibility of civilian uses for plutonium. It had begun to work on Rapsodie, its first experimental breeder reactor, which ran on plutonium. CEA engineers argued that Chinon's plutonium might go to Rapsodie, and eventually to future breeders. Since these breeders would generate electricity, it would be in EDF's financial interest to produce plutonium. Compensation would have to take this into account. Undeterred, EDF engineers calculated the financial benefit that the CEA would derive from processing the spent fuel and argued that this had to diminish whatever price EDF might eventually pay for breeder fuel.

CEA engineers tried another tack. Starting up any reactor involved adjusting the amount and distribution of fuel in the core, which in turn required removing some fuel rods before they were fully irradiated. Thus, the CEA argued, any reactor startup led to the production of at least some plutonium that would, almost incidentally, be of weapons grade (this was known as *plutonium fatal*, in the sense of "inevitable" or "fated"). Since EDF reactors would produce this plutonium on startup no matter what, the utility should not include it in its compensation calculations. But EDF responded that it could devise a startup phase that would *not* produce such plutonium. Besides, argued the Nuclear Energy Committee, it was still too early to know for certain how much military plutonium Chinon would produce, since EDF1 had not even begun operating yet. "Right now," it argued in September 1962, "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 sub-irradiated fuel."[58]

"Very objectively" in this case meant that EDF engineers wanted to assign a financial value to the loss of information they would suffer by giving plutonium to the CEA. This information had value on two counts: it would help them design EDF5, and it would enable them to develop better estimates for the economics of future reactors. The value of knowledge thus had to be quantified. In a process similar to the technopolitics of the competitive nuclear kilowatt-hour, EDF engineers were trying to reshape the terms of the debate in order to turn the liability represented by the CEA's plutonium demands into an asset.

Indeed, it occurred to them that plutonium production could be made to help rather than hinder the competitiveness of nuclear power plants. After all, the CEA agreed that making plutonium had financial consequences for power generation. What if these could be brought into the calculation of the nuclear kilowatt-hour in a systematic fashion? Excited by this possibility, the Nuclear Energy Committee proceeded to appropriate and refashion the notion of a "plutonium credit" in order to make EDF's reactors more cost effective.[59]

The plutonium credit had both technological and economic dimensions. The amount of plutonium produced depended on how long fuel rods stayed in the reactor core and on their level of irradiation. Too long a stay or too high an irradiation level would not produce useful weapons-grade material, and these conditions also held for material destined for breeder reactors. Producing a large amount of electricity involved keeping fuel rods in the core much longer and irradiating them at a higher level. But privileging the cost of the kilowatt-hour over the quantity of electricity produced meant that EDF engineers did not necessarily want to maximize the irradiation levels or the lengths of stay. Rather, they wanted to *optimize* these quantities in order to get the lowest possible kilowatt-hour cost. Once the fuel left the reactor, it eventually went back to the CEA for treatment or processing. EDF engineers wanted to create a scale that would assign a value to this fuel according to the amount of plutonium it contained. They could then take these figures into account in calculating a reactor's fuel cycle. Thus EDF would get to run its reactors under optimal economic conditions, and the CEA would still get its plutonium.[60] Although exactly how to calculate this scale remained unclear, EDF engineers appeared confident not only that they could come up with such a scale but also that the resulting plutonium credit, together with a new fuel rod design then under development, would make EDF6 competitive.[61]

The matter became even more complicated as the definition of "competitive" began to change and as shifts in the nation's political and economic climate raised the stakes even higher. The economic competitiveness of French technologies on foreign markets was becoming an important political issue. For the nuclear program, this meant that the gas-graphite design now had to compete economically with foreign designs. EDF's nuclear engineers were increasingly confident that they would, in the not-too-distant future, make a nuclear kilowatt-hour that could compete with the conventional one. But could they make a gas-graphite kilowatt-hour that could compete with kilowatt-hours produced by light-water reactors? The greater challenge posed by this goal soon became clear. Once again, EDF engineers invoked the plutonium credit to help them in this task:

> The competition that our system is likely to encounter in the near future from the boiling water system leads us to reconsider . . . pricing irradiated fuel [in light of] the prospect of breeder reactors. . . . Pricing breeders makes preparing a stock of plutonium economically interesting. 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.*[62]

The plutonium credit, in other words, would also help EDF's gas-graphite reactors compete with American light-water reactors (which did not, after all, produce nearly the quantity or quality of plutonium that gas-graphite reactors did).

The CEA did not deny that a competitive kilowatt-hour (of either type) was a desirable goal for the French nuclear program. But its engineers and directors resisted implementing EDF's plutonium credit. Perhaps because CEA leaders had come to recognize the ever-increasing techno-political importance of economic modeling as a mode of reasoning, the CEA had started its own small division of economic studies. Economists there set to work refuting the EDF's figures. Their studies argued that the high degree of uncertainty about plutonium's technical characteristics and economic future did not justify fixing a price for it. For one thing, a liberal, supply-and-demand type of market for plutonium did not exist. Even the United States and Britain—the countries with the most experience in producing and using plutonium—constantly changed their plutonium prices. For another thing, the "use value" of plutonium depended on which kind of reactor had produced it, the operational conditions of the specific reactor, the cost of processing the plutonium, and the element's end use. In other words, these reports implied, EDF had gotten it backwards: the value of plutonium could not be determined until the metal had completed the cycle for which it was destined. It was "*neither necessary, nor desirable* and in any case difficult," one report concluded, "to assign plutonium a price and to base a development policy for nuclear energy on [that price]."[63]

The two institutions had reached an impasse that could not be resolved by the men directly involved with the research, development, and operation of the reactors in question. EDF engineers had managed to renegotiate the terms of the plutonium dispute to include broad economic criteria, but this renegotiation did not necessarily arbitrate in its favor. Indeed, the economic language just highlighted the differences between the two regimes once again: the CEA advocated a more market-oriented approach to pricing plutonium, while EDF in effect wanted to use the price of the metal as another kind of state subsidy for nuclear power generation. These competing ideas about the market undergirded the systems analysis conducted by each regime, which meant that neither could prescribe a policy agreeable to both regimes. The matter (along with several other disputed issues) traveled to the highest administrative reaches of each institution. Finally, in mid 1965, the CEA's Administrator-General and EDF's Director-General signed a series of accords governing their financial relations. In the end, the plutonium agreement favored the CEA's approach more. The two men agreed to determine the price that the CEA would pay EDF for spent fuel on a yearly basis, using the year's current international rate for plutonium as an index. There would not, in other words, be a fixed, predetermined plutonium credit. But EDF engineers did receive some compensation: the CEA guaranteed that it would provide EDF with fuel of a specified quality; if the fuel didn't yield as much energy as promised, it would reimburse EDF accordingly.[64]

Industrial Competitiveness, Exporting Reactors, and the Future of France

In each case that I have examined so far, the technopolitics pursued by the two regimes gave them a distinctive voice in a broader debate about France's industrial and political future. Some of the technopolitical entities they created—including the competitive nuclear kilowatt-hour—became common currency in this broader discourse, reshaping the parameters of debate. Others, including the plutonium credit, did not.

Though necessary for political survival, reshaping the parameters of debate could be dangerous. Once a technopolitical entity became common currency, more players could enlist it (or even change it) to support their goals. This happened to the competitive nuclear kilowatt-hour. In the mid to late 1960s, it was redefined: the reference point for the gas-graphite kilowatt-hour was moved from conventional power to non-gas-graphite forms of nuclear power. This redefined comparison point, in turn, entailed a shift in the focus of debate back to the organization of EDF's reactor projects and its contracting industrial methods. This shift proved fatal to the programmatic authority of gas-graphite engineers, because the new focus involved elements that many other people and institutions could legitimately shape. Ultimately, this shift would cause engineers to lose control over program development policy altogether.

By the mid 1960s, most political and economic leaders agreed that France had recovered from the ravages of the war. But Charles de Gaulle's goal of national grandeur through technological prowess still seemed far off. Most French technologies did not appear to offer the diplomatic possibilities of which de Gaulle had dreamed. If the nation was to steer its own course in the Cold War, then it had to move beyond merely developing an industrial infrastructure. France had, most agreed, to develop technologies that could hold their own in the world's most advanced industrial sectors.

The articulation of this problem within the state had two dimensions, one represented by de Gaulle and one by his prime minister, Georges Pompidou. De Gaulle emphasized national grandeur: for him, it seemed, the symbolic value of industrial and technological development reigned supreme. Above all, he felt, this development had to promote French national independence. Pompidou emphasized instead the economic side of the issue. He felt that, above all, French industry had to become economically "competitive" in the international market: for him, the nation had to forge a distinctive identity primarily through its economic activity. The contrast between these two approaches would become particularly important for the nuclear program at the end of the 1960s. In the middle of the decade, however, these approaches were two sides of the same coin, for both advocated the same kinds of directions for industrial development. Both favored the development of large-scale technological programs (not just in the nuclear arena, but also in aerospace, computers, and electronics).[65] Both also favored a version of the "policy of champions," in which the state encouraged the formation of national industrial "champions" through industrial concentration in key sectors such as steel, electronics, automobiles, or aeronautics.[66] By 1964, de Gaulle had even conceded that the Plan could not, by itself, direct all of France's economic and technological progress. Some impetus had to come from private industry, which in turn needed more financial incentives to make long-term investments.[67] The private and public sectors had to cooperate in order for France to achieve political and economic greatness in the industrial arena. Such ideas had the full support of Pierre Massé and his staff at the Plan, who embedded them within the goals and strategies of the fifth plan just before Massé himself returned to EDF as the utility's new president in 1966.[68]

The most immediate consequence of this emphasis on foreign competition for the nuclear program was an increasing pressure to make French reactors competitive on the international market—in other words, to make gas-graphite plants exportable. The private companies involved in building the reactors had wanted to sell their expertise abroad for a long time. They now had increased state support for such ventures, and they began pressing EDF for help.

In fact, all the main players in the nuclear program fully supported the idea of making their technology exportable. But once again they had different ideas about how best to achieve this goal. Industrial contracting became the main point of dispute. Recall that in the early years of the program, the CEA's regime had favored a "policy of champions" and had hired a private consortium as prime contractor for its Marcoule site, while EDF's regime—mistrusting private companies—had preferred to manage

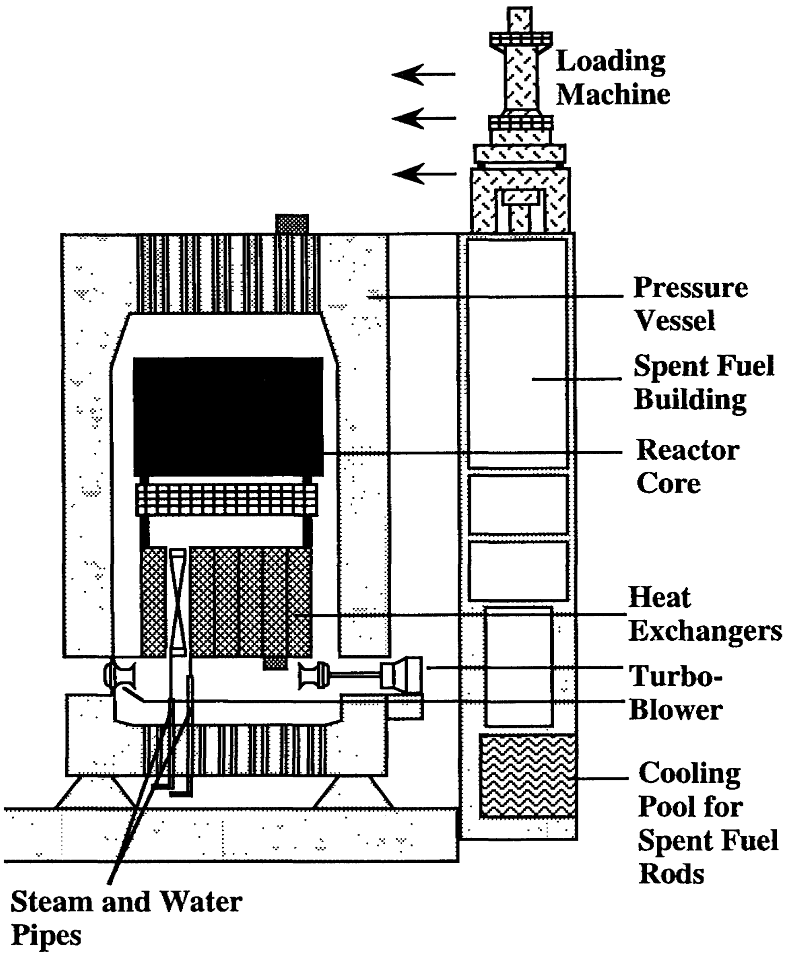

Figure 3.7
A schematic diagram of EDF4 (not to scale). Source: J. Grand and J. Hurtiger, "Aspect de radioprotection pendant les interventions de Saint-Laurent-des-Eaux," *Bulletin de l'ATEN*, no. 91 (1971). Drawing by Jay Slagle.

the bidding and construction process itself. Except for a brief flareup when EDF1's containment vessel cracked in 1959, this issue had lain dormant since the mid 1950s. It was reawakened by the loud, powerful voices clamoring for new kinds of competitiveness. The ensuing debate among engineers in the two regimes mixed personal animosity, anxious defenses of technical turf and expertise, and invocations of the national interest.

The debate started with the negotiations over EDF4. After going through several rather different possibilities and running multiple optimization studies, EDF engineers had decided to go with an "integrated" design. In each of the three Chinon reactors, the heat exchangers stood outside the pressure vessel that contained the core. In EDF4, destined for the utility's new Saint-Laurent-des-Eaux site, the heat exchangers would stand inside the pressure vessel, directly under the core (figure 3.7).

Optimization studies had shown this design to have several advantages, including lower construction costs and increased reliability.[69] Engineers expected EDF4 to have a longer life than its Chinon predecessors, so they reduced their initial payments by extending the amortization period (thereby increasing the reactor's short-term competitiveness).[70] Finally, their primary objective for EDF4's design was a nuclear kilowatt-hour that could compete with conventional power.[71] At the CEA, meanwhile, Jules Horowitz and some of the engineers in his Direction des Piles Atomiques had argued that, clever as the integrated design was, the program would do better simply to build an improved version of EDF3. The third Chinon reactor had encountered several construction problems, which CEA engineers worried had created "a very unfavorable impression of French nuclear technology." "This point," they continued, "seems essential to the CEA, which feels that it is indispensable that the next project demonstrate that a technically viable nuclear plant can be built in France in less than five years under satisfactory economic conditions."[72] The CEA thereby equated the national interest with demonstrable technical competence and argued that EDF4 should entail incremental improvements, not radical innovations. However, the EDF team, which equated the national interest with commercial viability, felt that Chinon's third plant simply could not serve as the model for a series of plants.

Though the EDF4 matter was settled in favor of the utility, engineers there continued to feel plagued by what they saw as Jules Horowitz's increasing encroachment on their territory. They felt he was engaging in "subversive action," trying to worm his way into EDF's work—"often without official instructions from the top, which ratifies [his actions] in case of success, but does not support [them] when EDF reacts violently."[73] The goal appeared to be "CEA hegemony over everything nuclear, and, in particular, the leadership of Mr. Horowitz in the domain of power reactors."[74] In one memo, one of these engineers spent four pages listing Horowitz's transgressions, accusing the CEA of withholding information and not working hard enough on the technical problems that most mattered to EDF. He gave a bitter analysis of the means by which the CEA succeeded in exerting influence (these included the scientific expertise of its personnel, its direct connection to the Prime Minister, and its role in the military program). Now, at a time when it had become extremely important to build reactors that held their own both politically and economically on the international stage, Horowitz wanted to interfere more than ever. EDF engineers hoped to use the issue of export to silence their opponent once and for all. "Where would the CEA proponents of export be today," one engineer asked, "if EDF had adopted Mr. Horowitz's point of view? EDF3 would be limited to 375 MW. . . , [and] EDF4 would be a duplicate of EDF3, a design completely surpassed by the British projects at Olbury and Wylfa."[75]

Horowitz felt equally hostile toward EDF, whose engineers, he said, opposed the CEA out of sheer stubbornness. EDF engineers did not have the proper respect for the CEA's expertise, and sought only to minimize the agency's role in power plant development as quickly as possible. They underestimated the technical significance of their early plants and were overly eager to implement innovations. This eagerness was especially foolhardy since EDF had only about 200 engineers working on the plant projects, "a high proportion of which are recent recruits or of a fairly low level (for example, from the Ecole Polytechnique Féminine)."[76] Clearly, Horowitz felt that women engineers (of which there were scarcely a handful in EDF's nuclear teams) did not have the ability to engage in so complex a task as reactor design.[77] EDF, in short, needed a humbler attitude.[78] The quarrels between the two regimes continued as teams fought over the design of cores and fuel rods for the next two reactors, and over the order in which they should be built.[79] Not everyone at the CEA shared Horowitz's willingness to quarrel over small details, but skepticism about EDF's ability to act in the national interest appeared widespread: "It would be regrettable," wrote the CEA's public relations manager, "if, instead of fighting for a more intimate role in these projects, the CEA . . . lost face in a non-existent battle. The real problem is not the relative order of the two plants, but the degree of confidence in EDF's commitment to the five year plan for developing natural uranium plants, on which hangs the future of civilian nuclear development in our country."[80]

Clearly the quarrels between the two regimes had gotten out of hand. Indeed, as the nuclear program became increasingly important in high-level government debates about France's political economy, these fights became outright embarrassments to top administrators in the two institutions. In an effort to make peace between the two groups of engineers, Robert Hirsch, the CEA's Administrator General, wrote to André Decelle, EDF's Director General, that "the French efforts to export" led the CEA to consider the development of an improved version of EDF4 urgent. Clearly, he conceded, EDF's integrated design had to form the basis for the future of the gas-graphite program over the next five years. The CEA was conscious of the increasing pressure of foreign competition and willing to undertake the research necessary to push gas-graphite design as far as possible.[81] Decelle reacted favorably to this overture, and the two leaders drew up guidelines for cooperating in the effort to make French gas-graphite reactors internationally competitive.

This truce did not have a lasting effect on the engineers in the two regimes, however. By mid 1965 they had begun quarreling again. This time, their confrontations did not revolve around what counted as good design criteria—Hirsch and Decelle had at least managed to silence them on that issue. Instead, they argued about the nuclear program's industrial contracting policy.

EDF's Direction de l'Equipement had continued to function as the prime contractor for reactor projects. For this purpose, it had created two Régions d'Equipement Nucléaire (REN1 and REN2) to supervise reactor construction. Both were run by engineers who had been around since Marcoule. They continued to believe that their nationalized utility could serve the public interest in a way no private company ever would or could. Blending in with the national political climate fostered by Pompidou and de Gaulle, REN engineers did not evoke the leftist dimensions of nationalization; instead they cast their arguments in terms of competitive pricing for foreign markets. EDF, they argued, should remain the prime contractor in order to start bidding wars between companies and keep construction costs down. Leading to cheaper reactors, this structure would serve the interest of foreign competitiveness as well as the public interest.[82]

Backed by CEA engineers, private companies argued otherwise.[83] They said that the policy did not allow them to get the experience they needed to export turnkey reactors. Because no single company had yet had the opportunity to coordinate the construction of an entire reactor, none could actually sell one 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 for such bids were rare or nonexistent.

REN engineers did not accept that only private companies could export French nuclear technology, but they did not pursue this point. They even agreed that the companies should have something salable to export. To this end, they offered some concessions. Designs for three reactors were on the table: two very similar ones at Saint-Laurent, and one rather different reactor at the new Bugey site. Rather than divide the designs up into dozens of subunits and request bids for each one, engineers offered to create larger subunits. Companies could then create medium-size consortia in order to bid for the subunits. For example, in the case of EDF4 (now called Saint-Laurent 1 or SL1) this meant that only seventeen contracts would cover 80 percent of the reactor. REN engineers quite liked this solution: though it made vigilance over cost overruns more difficult, it did continue to foster competition between the consortia, and it left the overall management of the project in their hands.[84]

Private industry and the CEA wanted to push EDF further. They wanted the utility to launch bids for "nuclear boilers." In this scenario, once an EDF team had drafted a preliminary design, it would accept bids from large consortia for the reactor's central heat-generating system: the core, the loading machine, the pressure vessel, and even possibly the control systems (what counted as part of the "boiler" was not completely clear). REN engineers hated this suggestion. One wrote in an angry memo: "Increasingly one hears, especially in the high spheres closer to Politics than to Industry, that EDF is not fulfilling its expected role with respect to French Industry, and in particular that the way it divides contracts prevents the birth or impedes the growth of powerful Consortia, the only ones capable, it appears, of exporting plants abroad. This affirmation, repeated so much that it is becoming dogma, is but a vulgar untruth."[85] The CEA had let itself be influenced too much by politicians, who should not be involved in industrial policy making. And private companies certainly could not be trusted to act in the national interest. In the matter of power plant development, only EDF engineers—by virtue not just of their expertise but also of their place in French society—were trustworthy. Reducing the number of reactor subunits would give private companies the responsibility of coordination, which rightfully "belonged to the state corps . . . because we are the only ones who can do this in an efficient manner."[86] Indeed, proposing the very concept of a "nuclear boiler" revealed the ignorance and incompetence of private companies: whereas boilers represented only 25 percent of a conventional power plant and therefore could reasonably be contracted out as a whole, the equivalent in a nuclear reactor represented 70 percent of the plant and was far more complex.

Defending their contracting methods, REN engineers wove the recent technical problems with their Chinon reactors (especially EDF3) together with their arguments about the social role of state engineers and their ideas about the national interest. The constant breakdowns and delays, they argued, were the fault of private companies. "First of all, you have to have something to export. Whether we like it or not, as long as we in France cannot offer nuclear plants that function normally and give their user, in other words EDF, full satisfaction, then only political pressure or exorbitant financial advantages can lead to the export of nuclear plants."[87] Just as EDF1's cracked vessel had caused political problems for the utility, so had EDF3's heat exchanger problems. EDF engineers, however, did their best to blame the builders, whose lack of experience had caused seemingly unending delays in the reactor's startup.

Ultimately, claimed the engineers, the real issue was who could best represent France. In a passionate statement, one REN2 engineer declared:

> With two exceptions . . . all the plants exported to normally developed countries [*sic*] are American, that is to say designed by a development office and constructed by specialized Builders, most often hired after open, international requests for bids[.] I emphasize this point, because the way that GE and Westinghouse function is much closer to EDF's [methods] than to the way the members of French or English consortia "divide the pie." . . .
>
> When Parliament created EDF in 1946, it made a national Consortium composed of Companies specializing in the construction and operation of power plants, of whatever type. In one fell swoop, this brave gesture put a French Company at the same level as the largest American Companies, with means that no French Industrialist could have dreamed of before. . . .
>
> I think that the success of our Establishment, which is stunning despite all the sarcastic comments . . . just proves everything I have been saying. . . .
>
> It would thus be only natural that we could, of our own accord, sell plants abroad the day that we think it's reasonable to do so, and with the Builders that the Customer and we will have chosen. We know from experience how much confidence we inspire abroad, we who are not tied to any bank, to any factory, [or] to any Consortium—and this is not the case for the Americans. Any other solution would certainly be doomed to failure. . . .
>
> Let us thus play our role, both Abroad and in France. . . . For twenty years, EDF has forged for itself competent, devoted, dynamic, and disinterested teams. To substitute for them less dynamic, less competent, and definitely not disinterested Industrialists is not a policy but an abdication.[88]

This passage shows how many heterogeneous issues EDF's nuclear engineers marshaled in defending their contracting policy. They fully accepted the export agenda outlined by the Plan and the government. They did not, however, agree with the policy of national champions—at least, not champions who came from private industry. Comparing EDF's methods with those of American companies dissociated industrial practices from their political overtones. Thus, EDF's contracting policy appeared well tested in the capitalist world. EDF engineers invoked the utility's glorious history, but instead of stressing the social and political benefits of its nationalized status they stressed the industrial benefits: only EDF was large enough to stand up to the Americans. Likewise, only EDF was "disinterested" enough to manage the export of power plants—both because it had no ties to private financial concerns and because its state engineers were inherently interested only in the good of the nation. In the face of the threat to their expertise and authority, the engineers jettisoned the leftist dimensions of their regime. They attempted to reconfigure the political meaning of their practices to make them appear more in line with the national policies emanating from the Plan. In so doing, they tried to walk the line between Georges Pompidou's emphasis on economic competitiveness and Charles de Gaulle's emphasis on French cultural superiority. Walking this line made it all the more crucial that the EDF engineers reaffirm their identity as loyal and impartial public servants whose only thought was the best interest of the nation.[89]

EDF's nuclear technopolitical regime had taken a risk in trying to set an example for the rest of French industry. In the process of trying to enroll the state in its industrial policy, the regime ended up invoking the wrath of a government far more interested in closely directing that policy than its Fourth Republic predecessor had been. The president, the prime minister, and the Plan all pushed for "international competitiveness," and all believed that the promotion of "national champions" could best achieve this goal. For de Gaulle, they symbolized national independence and glory. Pompidou and the planners thought they would spur economic growth.[90] The Plan had quite explicitly emphasized "the need to pursue the . . . concentration of French industry to increase its competitiveness and allow it to confront the powerful foreign companies as economic opening occurs."[91] Further, nobody was particularly happy with EDF's nuclear program—especially not Charles de Gaulle. In 1966, he hoped to inaugurate EDF3 personally. Because of the technical problems experienced by the reactor, Pierre Massé (who by then had returned to EDF as its president) suggested that de Gaulle inaugurate the new tidal power plant at La Rance instead. De Gaulle reluctantly agreed, but he was angry with the utility. "I must say," he declared coldly during one ministerial meeting, "that we would not be where we are had EDF followed the wise counsel of the CEA."[92] His increasing displeasure with the utility's nuclear technopolitics echoed throughout the government.[93]

The regime faced threats from within the utility as well. A change of the guard that had been underway at EDF for some time had been accelerated by Massé's return. Massé himself strongly supported the notion of international competitiveness. He had chosen as his second in command Marcel Boiteux, whose economic expertise has already been mentioned.[94] These men and others under them had more sympathy with Pompidou's vision of France's future than with that of their own nuclear engineers. They certainly did not share a belief in the inherent superiority of state engineering or nationalized companies, and they had a markedly different domain of expertise. They did not, therefore, advocate the same technopolitics. Instead, the new economist-managers advocated a strategy closer to that laid out in the fifth plan and supported by Pompidou. Against the vociferous protests of their engineers, these managers took a first step toward changing EDF's nuclear contracting policies. For the two projected reactors at Fessenheim, EDF's newest projected nuclear site, the utility would launch two kinds of requests for bids: the first would follow the utility's traditional policy, and the other would ask consortia to bid on "nuclear boilers."[95] This way, the consortia might get the experience they needed in order to export their skills and technologies.[96]

This decision assuaged private industry, the government, and the CEA, but it angered the engineers and labor unions at EDF. Engineers continued to write furious memos defending their previous practices.[97] The political dimensions of this decision were such that even labor representatives, who had remained silent on this issue as long as the policies advocated by engineers dominated, got involved in the fray. The Confédération Général du Travail, the communist-dominated union, saw itself as the last defender of the social and political dimensions of nationalization. Claude Tourgeron, a CGT militant who sat on EDF's board of directors, argued furiously against the decision before it became final, declaring that it was bad for the nuclear program, bad for EDF, and bad for the nation. The companies bidding for the smaller sub-lots in the traditional request for bids, said Tourgeron, belonged to the very consortia that would submit bids for the "nuclear boiler." They would play with the numbers so that the consortia bids would—artificially—appear to produce cheaper reactors than the individual bids. One thing would lead to another, and this mode of bidding would prevail. Private consortia would become prime contractors, and hundreds of EDF employees would be out of work. Finally, Tourgeron argued, France would never realistically export gas-graphite reactors. "Underdeveloped" countries would not want nuclear plants, because such plants were profitable only when they were very powerful, producing more energy than such countries would ever need. And industrialized countries would want American plants because they seemed cheaper. Gas-graphite plants made sense for France only because France had its own natural uranium supply. Thus the two consortia proposed would have only one customer: EDF. This, in turn, would artificially inflate the cost of nuclear power plants. In sum, consortia bids were bad for the national economy. Other union members echoed these sentiments.[98]

A deeper issue also ran through the dispute over contracting: the changing meaning of nationalization within EDF. The CGT and the nuclear engineers shared an understanding of nationalization that rested on a leftist vision of the socioeconomic order. For them, acting in the national interest meant that a nationalized firm would supersede any and all private companies. As we have seen, though, by the mid 1960s the engineers who directed the reactor projects were not committed to this leftist interpretation. Indeed, most (particularly those who did not belong to the CGT) felt that private industry should grow strong in order for the French economy to flourish—as long as helping industry grow strong did not mean relinquishing control over plant development. The CGT, of course, did not concede these points. Roger Pauwels, another militant who sat on the board of directors, snidely remarked that some of the other directors seemed to think that EDF's mission was to facilitate the development of private industry. Indeed, this was not so far from the mark. Pierre Massé responded to this accusation primly: "That is indeed one conception of the role of the nationalized firm, and . . . we could spend a long time debating this." Such, at least, was the response registered in the first version of the minutes. The official version of the minutes amended this formulation: "The proposal [for bidding by consortia] has the benefit of the entire national economy in view, a benefit in which EDF will share."[99] We can only surmise that EDF's president wanted the economist-managers' competing claim to the best interests of the nation to go on record in a stronger way. Clearly their understanding of nationalization and public service had no leftist connotations. For them, the main mission of a nationalized firm was to foster the nation's industrial growth—and that, necessarily, meant implementing policies favorable to private companies. The fact that the Plan supported such policies served as proof that they were in the national interest.

One of the problems that engineers encountered in the battle over industrial contracting was that the hybrid nature of their two most important technopolitical tools—the competitive nuclear kilowatt-hour and optimization models—made these tools easier for others to appropriate. Unlike reactor designs, these two entities did not fall under the exclusive purview of engineers. Both were entities that had first emerged in economic spheres. Engineers had reshaped them—indeed, they had made the existence of the competitive nuclear kilowatt-hour possible—but they did not fully control them. Industrial leaders, planners, and utility economists did not agree that engineers were the most qualified people to define the relationship between industrial contracting and the competitive nuclear kilowatt-hour. During the Fourth Republic, the government was too unstable and had too many other preoccupations to address industrial policy in any depth. A decade later, however, industrial policy had become one of the Fifth Republic's top priorities. Private companies had recovered from their wartime loss of reputation, and economists had thoroughly penetrated the state and its institutions. In the end, engineers did not (or could not) devise technopolitical tools of the resiliency they had managed earlier. The forces arrayed against them were too strong, and they were too weak.

Like the engineers, EDF's leaders had been trying to escape the increasing interference of the CEA. Their solution, however, was one that engineers could never have considered seriously: 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.

*

In the Fifth Republic, as in the Fourth, engaging in technopolitics helped engineers expand their sphere of influence. Designing and building nuclear reactors posed real and difficult technical problems; it also posed difficult political problems. Often these were one and the same. EDF1's cracked containment vessel was not simply a puzzle in steel welding; it was also an embodiment of EDF's development strategy and of its relationship with the CEA. The competitive nuclear kilowatt-hour was not a transparent technical concept; it was the product of the complex technopolitics of optimization. Producing plutonium in civilian reactors was neither a purely technical nor a purely political problem; it was a process subject to negotiations among two technopolitical regimes and the state. In all these cases, engaging in technopolitics provided a way for engineers and managers not just to solve the problems at hand but also to spread their authority beyond the confines of their institution and to promote their vision of France's (technological) national identity. The government and the Plan might define "competitiveness" as a desirable goal for France, but they could not materialize that competitiveness. De Gaulle might use the nuclear program as a symbol of French power, but he could not single-handedly determine the myriad ways in which nuclear technology would become entwined with France's future. Engineers produced material manifestations of these visions for France's future and symbols of its identity. Technopolitical practices and artifacts thus provided means not only to exert influence over other institutions but also to stake out a place in larger debates about industrial policy, international competitiveness, and the future of the French nation.

At no point were engineers reluctant to expose the political dimensions of their work. On the contrary, they were explicitly addressing their work to broader political issues. Sometimes, indeed, they were using those broader issues to legitimate their practices: in the debates over industrial contracting, for example, engineers recast the political meanings of their contracting policy to place it in the context of Fifth Republic priorities. In that case, politics was not just a goal but also a resource for engineers.

That example, together with the introduction of optimization techniques and the invention of the competitive nuclear kilowatt-hour, also reveals the risks of technopolitics for engineers. Admitting heterogeneous practices and criteria into their work opened the door to other forms of authority and expertise. EDF engineers adopted optimization studies in part to strengthen their regime in its programmatic battle with the CEA. But those very techniques made their authority in their own regime vulnerable by privileging economic modes of reasoning, and thus privileging the authority of economic experts. EDF's economist-managers used those same kinds of practices to discredit the gas-graphite design altogether.

4

Technological Unions

To what extent did social groups other than technologists, engineers, and scientists incorporate technological prowess into their visions of French national identity? How did they do so, and to what ends? All too often, historical accounts of technological change in the twentieth century confine themselves to the designers of artifacts and systems. We know a tremendous amount about the creation and spread of technological systems, but relatively little about how the people who work in those systems think about technological change and its role in their lives. Yet their point of view is crucial, not only for its own sake but also for the sake of understanding the multiple dimensions of technological change.

Labor union discourse provides a good entry point into these questions. Unions have a powerful voice in French society. From an American perspective, they function almost like political parties: each of the three major unions has a distinct ideological platform, which they rehearse in their public statements and wield in their strikes. The unions have a complex structure: they are organized into national confederations, each including numerous trade federations, which in turn are divided into local sections. For example, the Confédération Général du Travail groups together trade federations for many sectors: electricity and gas, aircraft, chemical, metallurgy, banking, etc. The other two unions also have their own trade federations for each sector. Unions express general ideological positions through their confederations, leaving specific sectoral demands to the federations.[1] It is at the confederation level, therefore, that unions contribute to national political discourse. And it was at the confederation level that unions participated in the national conversation about technology, politics, and national identity in the 1950s and the 1960s.

In chapter 1, I examined how technologists as a group presented a vision of French national identity that revolved around technological prowess. In the present chapter I look at the visions offered by France's