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A sociotechnical analysis of the French FBR programme: successive forms of evaluation[1]

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Based on a retrospective study of the French Fast-breeder Reactor (FBR) programme, this paper aims to show the dynamics of FBR demonstrator evaluation, with methodological inputs from the "Science and Technology Studies" branch of sociology. Such a reactor has to demonstrate the feasibility - including safety, technical and economic viability - of a promising technology regarded as a potentially inexhaustible energy source for the future. Until the mid-seventies, the need for an FBR fleet was regarded as urgent, entailing a focus on demonstration reactors to prove "technical" feasibility. But after the mid-seventies, the purpose of evaluating FBR projects was to prove the technical and economic viability of the programme, as well as its safety. The analysis of the Superphénix case is used to illustrate the difficulty of reconciling the three elements of assessment in a changing context, where the respective weights of the various criteria evolve in a dynamic fashion: it calls for an examination of the implicit specifications of demonstrators.

Introduction: qualifying a major technological project

Fast-breeder Reactor (FBR) technology was developed immediately after the Second World War, with prototypes of ever-increasing sizes in different industrialised countries (SAUVAGE 2013). These countries considered that a system composed of a fleet of commercial fast breeder reactors and fuel reprocessing plants should be the logical end-point of any viable nuclear programme. Indeed, thanks to "fuel breeding", this technology offers the perspective of a virtually inexhaustible source of energy by using the potential of uranium in proportions that range from 50 to 100 times higher than what is possible with water reactors (which currently constitute the majority of the world reactor fleet).

Fuel breeding is made possible by a "fast-neutron" regime, which necessitates using a liquid metal as a heat-transfer fluid. Sodium was chosen because of its high thermal conductivity; it is nevertheless known for its reactivity with water and oxygen. This technology is often referred to using the abbreviation "fast reactor" or by alluding to its "fast-breeder" potential.

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Yet there is nothing linear about the way the technology has developed: depending on the time and country, development has involved phases of acceleration, slowdown, stoppage and renewal.

In France, in order to learn from the past, experts in this technology implement "operational feedback" and record what they have learned from the technical choices that were made, from global concepts to fine steel grades. Nevertheless, the story of the development of sodium-cooled fast-breeder reactor technology is not just one of technical objects. By adopting the sociology of science and technology perspective and combining these various aspects, one can offer new insights.

This article focuses on one of the many lessons learned from this research, that of the crucial role that evaluation plays in explaining the phases of slowdown or acceleration of project development. In this context, evaluation is understood in its broadest sense, as being an appraisal of the technology, making it possible to qualify it from a technical, economic or safety standpoint. The result of these evaluations is that every apparently technical decision, such as to build a prototype, to make improvements to safety or to recalibrate the project, is in fact the realization of the discourses which qualify the project.

We will first set out the conditions and line of attack of the research; we will then present the three phases of the history of Sodium-cooled Fast-breeder Reactor technology in France, in relation to three different ways of assessing the technology. In the final section of our article, we will discuss several key issues relating to the problems involved in assessing prototypes and demonstrators.

The sociology of science and technology applied to the Superphénix project: a demanding and comprehensive method

Our research was based on extensive reading of the existing literature, the consultation of archives and approximately thirty interviews with project actors. Some of the interviewees were involved in the first steps of fast-breeder technology, before reorienting their careers towards other areas of nuclear power; others were involved from start to finish, devoting their entire careers to the development of the technology; finally, some came from other professions and were only briefly involved. We met scientists and engineers who took part in the design, construction or operation of Superphénix, as well as members of the board of directors, experts from the nuclear safety authority, and certain experts and opponents critical of the technology.

The history of fast-breeder technology in France, and of Superphénix in particular – a reactor which was stopped earlier than planned – is a controversial one. Researchers who examine this case are confronted with a profusion of written documents of a highly diverse nature, with numerous arguments for or against. Within the literature we studied, we found a hundred or so publications on fast-breeder technology, along with extensive press archives.

The initial difficulty was one of developing a methodological and interpretive framework which would make it possible to organize these sources in a coherent manner. The method we chose is rooted in the sociology of science and technology and in particular in the work by Bruno Latour (1996), "Aramis or the Love of Technology". This book traces the history of a public transport project called "Aramis" which was intended to serve southern Paris with the combined advantages of rail transport and individual cars, but which never reached the commercial stage. Above and beyond a case study, this work offers lessons on factors for success or failure for such innovative projects, along with a methodological stance from which to talk about the past from the point of view of the researcher's situation in the present. The narrator talks to his student as follows:

"*Always assume that people are right, even if you have to stretch the point a bit*. […] *otherwise, you play the sly one at the expense of history. You play the wise old owl.* […] *life is a state of uncertainty and risk, of fragile adaptation to a past and present environment that future cannot judge.*" (Latour 1996, p.35-37)

Another requirement is that of taking a rigorous critical approach: such social science research involves an iteration between sources, theoretical frameworks and constantly revised intermediate hypotheses, until one succeeds in producing an interpretation which, in a coherent fashion, brings together and integrates all of these elements in a "reciprocal double-fitting" (Baldamus quoted by Olivier de Sardan 1995). This critique-based approach is common to the sociology of science and technology or to history (Prost, 1996). In particular, we refused to reread the history of a technology on the basis of its developments which were known to the researcher but unpredictable for the actors in the on-going project, as illustrated in this quote from Rip & Kemp (1998):

"*The direction of technological development was determined by the actual paths and the expectations of what could be next steps [...]. Our retrospective idea of steps in the direction of the situation as we know is irrelevant*".

These methodological requirements first of all allowed us to interact with actors who have been involved in the development of FBR technology for many years, and then to develop a new history.

Using numerous existing accounts of the history of sodium fast-breeder technology in France, some of which separate the technical from the political, our approach offers a new interpretation that combines both of these dimensions. During our research, we felt the issue of FBR project evaluation to be crucial: it traverses the entire period under consideration, using different modalities.

A history in three periods

This research enabled us to propose a "socio-technical" chronology in three periods which interlink visions of the future with evaluations of prototypes and of the potential of the technology:

• The beginnings: demonstration of the feasibility of fast-breeder technology (1954-1975);
• from the programme to construction of the "industrial prototype": the evaluation broadens out to a triptych – technology / economics / safety (1975-1986);
• and finally, the challenge of operation: justifying safety and revamping objectives (1986-1997).

This chronology will allow us to show that each stage of the development of fast-breeder technology is the result of an evaluation of its necessity and potential. More particularly, the decision of whether or not to move on to the next stage of the programme was always the result of an assessment of the programme's merits, based on criteria which evolved over the many decades under consideration.

The beginnings: demonstration of the feasibility of fast-breeder technology (1954-1975)

In France, FBR projects were launched throughout the 1950s and 1960s, a period when a vision for the future - which was shared by the decision-making bodies – concluded that such developments were necessary, due to:

• the forecast of an increasing demand for energy leading to the development of nuclear power;
• concern regarding the depletion of energy resources and the increasing cost of uranium, giving a significant advantage to FBR technology due to its ability to regenerate its own fuel;
• concern for national energy independence;
• a vision for the nation's future which would come about through national technologies;
• the technical and economic potential of these reactors deemed to be highly promising.

We might view the development of experimental and then demonstration reactors as a consequence of these visions for France's energy future, within a climate of international competition for technological development. In France, FBR project developers were driven by the conviction that this technology would receive overall support if they could provide proof of its technical feasibility. To this end, "RAPSODIE", the first experimental reactor in France, was developed and built in Cadarache by the *Commissariat à l'Energie Atomique (CEA)* (the French Atomic Energy Agency) with a contribution from Euratom; nuclear reaction diverged in 1967 (Vendryès, 1997).

At the end of the 1960s, debates in France on the type of nuclear technology to retain for the industrial fleet were an opportunity to compare different visions for the future: on the one hand, the rhetoric of national technological excellence supported the graphite-gas technology developed in France; on the other hand, the rhetoric of the economics of energy supply favoured light-water reactors (LWR), available from American constructors at very attractive prices. Chosen in 1969, LWRs were seen as a short-term economic solution to meet energy needs. Everyone then agreed that a future nuclear fleet should be based on FBRs, a technology which would combine the stakes of national technological excellence with those of an affordable electricity supply (Hecht, 1998). In the long term, FBR technology, the cornerstone of the nuclear system, should allow the nuclear industry to supply abundant low-cost energy to the entire world. Over the medium term, the challenge for competing countries was therefore to be the first to develop plants which would be industrial (i.e. powerful and reliable) and commercial (i.e. capable of equipping the national fleet and of being exported).

In France, the next stage was to build a 250 MWe (MegaWatt electric) prototype, the characteristics of which were inferred from an industrial 1000 MWe pre-project (Vendryès, 1997). The Phénix reactor diverged in 1973, and was hailed as a technical success, achieved within the deadlines thanks to an innovative "integrated project" organisation which brought the project owner and the engineering and construction company together within a single project team.

During this period, the elements of project evaluation were as follows:

• the vision of the future of energy made FBR technology necessary over the short-medium term;
• the challenge was to prove its feasibility, and projects were essentially analysed from a technical standpoint with a safety condition, control of which was given to an *ad hoc* department within the CEA (Foasso, 2012). Under such a regime of research and demonstration, the purpose of an experimental installation or prototype was to answer the implicit question: "does it work?", with a cost criterion expressed in terms of project budget.

At the beginning of the 1970s, the evaluation was positive: the satisfactory commissioning of Phénix was proof of the viability of FBR technology. The decision was therefore taken to launch the development of the Superphénix industrial prototype, which would mark FBR's move from the experimental era into the industrial era. Five times more powerful than Phénix, Superphénix was launched as an "industrial and European prototype".

From the programme to the construction of an "industrial prototype": evaluation expands into a technology / economics / safety triptych (1975-1986)

During the decade constituting the second period of our chronology of the French FBR programme, the development and evaluations of FBR projects evolved in parallel in various areas which we will set out in the following order (the order is theme-based and not chronological):

a) The Superphénix "industrial prototype" was built on the Creys-Malville site, located in the south-east of France, between Lyon, Grenoble and Geneva;

b) Safety assessment took place as part of the new institutional framework dedicated to industrial plants; economic evaluation found its material translation within EDF's plant design division, in an effort to make the reactors of the future fleet less costly;

c) The question of the future need for fast-breeder technology and the shift to the industrial fleet was also subject to evaluation; the characteristics of the Superphénix industrial prototype were subject to "expert" militant criticism which echoed academic criticism from French research laboratories or foreign institutions. In particular, this criticism included an economic assessment.

A "prototype" with highly "industrial" framing

In a manner which was more visible, the 1975-1986 decade was that of the Superphénix "industrial prototype" construction. But whereas the demonstrators of the previous period (Rapsodie and Phénix) had had to prove the technical feasibility of fast breeding within a research agency (the CEA), Superphénix's allotted task was far broader. Superphénix now had to validate the full-size industrial operation of a technology deemed to be ready for commercialization. This framing was embedded just as much in Superphénix's technical characteristics (a size of 1200 MWe featuring industrial devices) as in its organisational characteristics: the project owner was a joint venture company made up of French, Italian and German electricity suppliers. It ordered the reactor from Novatome, a subsidiary of CEA (to which the latter had sold the licence) dedicated to the marketing of this technology. These are but a few examples of a complex organization targeting the serial production and commercialization of FBRs in the near future (Jobert & Le Renard, 2014).

At the worksite of this "world-first" programme, one technical challenge followed another. The project engineers speak volubly about this difficult job of work where they used all their technical and innovation skills to resolve unprecedented problems. With the help of the sociology of science and technology, we can consider the construction phase as a time when the project was weighed down by all of the technological detours or "scripts"(3) that had to be invented in order for it to take the form of a real prototype plant (Le Renard, 2015). The finished prototype was thus not exactly the same as on the pre-project plans: it was more complicated, and the provisional budgets and scheduling had to be extended. One key question is therefore to find out whether the way in which project promoters talk about this technical installation is coherent with its new material form (Latour 1996, Duret et al, 2000).

(3) To state Latour's (1996) terms in a simple manner, a script may describe the link between the technical device and its finality in both directions: the finality's in-scription into the technique (using additional devices where necessary) or de-scription of the human uses that the technical device supposes.

An industrial prototype assessed in terms of safety and affordability

In parallel to this huge worksite, though in a less visible manner, economic and safety evaluations were of increasing importance during the decade under consideration. In France, the Service Central de la Sûreté des Installations Nucléaires (SCSIN: Central Service for the Safety of Nuclear Installations) was created in 1973 as part of the French Ministry of Industry: Superphénix, which prefigured a future nuclear industrial fleet was very carefully examined by this department, which was no longer part of the CEA. Modifications had to be made to the prototype to take account of earthquakes and the evacuation of residual power; these modifications were necessary for the project to take its place in the reality of a regulatory safety regime at a given point in time. Just like the detours that proved necessary to resolve the practical difficulties during construction, these modifications changed the original pre-project plans and led to increased costs.

In France the evaluation of energy production technologies from an economic standpoint began during the post-war period (Hecht 1998). At the end of the 1970s, planning for the future fast-breeder fleet was based on ratios which predicted a drop in the specific investment costs when the size of the reactor increases, and lower investment costs for a series reactor compared to a prototype reactor.

As from 1980, the decision-makers deemed that as it stood, Superphénix was too costly for industrialisation. The engineering teams in Lyon worked on defining the "basic design of a pair of 1450 MW Superphénix II reactors" (Quilès, 1981), in an attempt to simplify the prototype so as to meet competitiveness requirements.

EDF's senior management and the French Ministry of Industry wished to have a full year's worth of feedback on Superphénix's operation before making any decision to commit to an industrial fleet (Finon 1989): as a general principle, commitment to an industrial fleet was conditionally validated and postponed to a later date. Superphénix henceforth became a one-off "industrial prototype".

Assessing the long-term need for fast-breeder technology

Parallel to the construction of Superphénix, and to the increasing importance of evaluations, during the 1973-1986 decade, the slowing demand for energy, due to the economic slump which had followed the 1974 oil crisis, began to eat away at the urgency of developing a fast-breeder fleet. Then in the mid-seventies, orders for nuclear reactors in the United States were stopped, causing a sudden slowdown in growth forecasts for nuclear power worldwide. During the years that followed, the perspective of uranium depletion over the long term disappeared, and the urgency for a fast-breeder programme consequently diminished even further. As the decade advanced, plans for FBR industrial fleets were steadily postponed, with different representations depending on the actors and countries.

The way the future is envisaged is a determining factor for evaluation and for resulting decisions. During the previous period, developments of fast-breeder technology were decided on the basis of an argument of necessity: it represented a source of inexhaustible energy which justified costly developments in order to prepare for the future; the prospect of growth in energy demand which had given rise to Superphénix seemed to have stabilized. But during the following decade, this argument of necessity had to coexist with economic evaluations which made FBR a contingent technology for which it was necessary to evaluate the service provided in terms of cost and possible alternatives.

"Expert" militant criticism echoes academic criticism

In the debate, affordability therefore tended to overshadow the issue of proving "technical feasibility". Economic evaluation made it possible to summarise the technology's evolutions and context. Decision-makers made use of this to postpone commitment to an industrial fleet while building Superphénix, a one-off "industrial prototype".

The economic assessment of fast-breeder programmes took on new dimensions at the beginning of the 1980s, when academic economists examined the dossier and pointed out – often in an accusatory manner – the successive revisions of cost estimates for fast-breeder projects, depending on the actors and on the criteria taken into consideration (Finon, 1982). They challenged the hypotheses and ratios used by research agencies. Their evaluations made the extrapolation from prototype to industrial fleet in line with their own criteria, and they invalidated the utility of an FBR fleet for electricity production, on the basis of cost overruns and the technical problems of the prototypes built. This economic analysis was one area of "expert" militant criticism that was less visible than the radical activism (especially the 1976-1977 demonstrations which marked people's memories). This "expert" criticism came from associations, university researchers, physicists and economists, who echoed the critical stances of Anglo-Saxon countries, and underlined the assessments of FBR safety and technology carried out in those countries.

Expert reports commissioned by institutions in the United Kingdom and the United States also examined the potential and the costs of fast-breeder technology. As early as 1976, the Royal Commission on Environmental Pollution concluded that fast-breeder reactors constituted a form of insurance against a possible depletion of energy resources in the future (Flowers, 1976). On this basis, the commission determined that it was preferable to delay commitment to the 1000 MW commercial demonstration plant that was envisaged at that time in the United Kingdom. In 1984, the House of Commons Committee of Public Accounts confirmed these orientations (Lehtonen & Lieu, 2011). In France, "associations of critical experts" built up arguments that amplified these stances. Their criticism related to the modalities of the Superphénix project, in particular to its size: they felt it was premature to build an industrial-size reactor. In France, the issue was debated in public (but not institutional) arenas (Bériot & Villeneuve 1980, Brugidou & Jobert 2015), and the government confirmed the importance of energy independence, which justified Superphénix (Le Monde, 1980).

In conclusion, regarding the development of FBR technology, the decade from 1975 to 1986 should not be limited to the Superphénix worksite alone. Compared to the previous period, the assessment broadened its scope to a trio of dimensions that had to be held together: a prototype which must prove its technological feasibility whilst at the same time guaranteeing safety and affordability. Measures to ensure safety, along with the imponderables inherent to the process of technological innovation led to technical modifications being made to the prototype. This added to the cost of the project at a time when requirements were becoming increasingly ambitious.

The discourses assessing the success of the technology or, on the contrary, the "failure of fast-breeder reactors" (Finon, 1982), were based on feedback from the first reactors, which they extrapolated to the future industrial fleet. The evaluation of fast-breeder technology became an academic (especially in economic science) and institutional activity (institutions in the field of nuclear energy assessed the safety, opportunity and time frame of an industrial fleet, on economic bases). These different fields were linked: the need that one might have for the technology rendered the imposed competitiveness criteria more or less strict – which was reflected in the calculations that included different trajectories for forecasts of the cost of uranium.

During this decade, what was asked of demonstrators was no longer to simply "prove that it works": the debate related to the capacity of the prototypes to provide proof that the technology could satisfy evaluations with regard to the three aspects of technique, safety and economics. As requirements became more ambitious, viability was called into question. The prospect of an industrial fleet was postponed to sometime in the future, with support for FBR technology gradually becoming conditional.

The operation hurdle: justifying safety and revamping objectives (1986-1997)

During the third period of our FBR chronology in France, evaluation activity, now official, took place in a public context and was the subject of discussion in more wide-reaching arenas. To simplify matters, we will split this period in two, even though some of the developments were concomitant: first of all, the early years of Superphénix's operation were marked by assessments of its safety; then, discussions on the reconversion of Superphénix into a research facility gave a new turn to plant evaluation activities, the criteria for which were changing once again.

The early years of Superphénix's operation were marked by assessments of its safety

The operation of Superphénix as an industrial plant at the Creys-Malville site began in 1985. It was operated as part of EDF's nuclear fleet, alongside plants using the more proven LWR technology. As for other innovative projects, early operations had their fair share of technical difficulties. In March 1987, a sodium leak occurred in the fuel storage tank; it was replaced by a "fuel transfer unit" which performed only some of the original functions (Jobert & Le Renard, 2014). The modified Superphénix was thus no longer truly representative of the way in which the planned industrial fleet would be operated. In 1990, a pollution of primary sodium led to a lengthy phase of public questioning about the safety and purpose of Superphénix: would it not be better to convert it into a research facility? During four years of investigation and debate, the plant was stopped, and major works were required for safety reasons. It finally started to operate again in 1994, but another leak, this time argon, meant a further six months of stoppage.

Following the sodium leak in the fuel storage tank in 1987 and then the oxidation of primary sodium in 1990, the safety of Superphénix was subjected to a process of in-depth expert analysis that culminated in reports from the DSIN (French body responsible for the safety of nuclear installations which took over from the SCSIN in 1991). What was new in the 1990s was the public nature of the evaluations and debates: official reports were made public, and the safety of Superphénix was also discussed by the parliamentary office for the assessment of scientific and technological choices (OPECST), created in 1983, which allowed concerned groups and academic experts to voice their views. They dealt with the issue of the fuel storage tank, the risks of hydrogen or of sodium fires, relating not to a research installation but to a reactor which was industrial by its size, by its operation as part of EDF's fleet and by the future FBR fleet that it should prefigure.

From this period onwards, the project leaders put forward the notion of technical success: operating time was compared not to total operating time, but to time without any "administrative blockages" (Birraux, 1992). Yet the purpose of operating Superphénix was not just to demonstrate technical feasibility; in the post-1986 world, marked by the aftershock of the oil crisis, Chernobyl nuclear accident and the sodium fire at the solar power station in Almeria, discourses on opportunity were less unequivocal, and the challenge for the installation became that of "proving that it is safe". Alongside this institutional process of inquiry, Superphénix's safety was the subject of open public controversy.

Furthermore, safety improvements led to significant increases in costs which weighed on the plant's financial results and hence the technico-economic evaluation of fast-breeder technology. In the 1970s, actors believed that the technology was ready to enter a commercial phase; in the 1990s, it was struggling to live up to its promise when confronted with the combined demands concerning technique, economics and safety, in a context where the need for an industrial fleet was diminishing. This was one of the reasons why, in the early 1990s, public authorities considered converting the commercial demonstrator into a research facility.

Converting Superphénix into a research facility

In 1990-1991, the French Parliament began a process that "framed nuclear waste as a political issue", (Barthe 2006, 2009) leading to the "Bataille law" of 31st December 1991. This law provided for a re-examination of how nuclear waste should be processed, notably introducing a research programme to test "incineration". Superphénix was one of the reactors likely to be used in the programme.

In May 1992, while Superphénix was stopped, the very opportunity for its operation was discussed during a public debate on "the possibility of restarting Superphénix and the future of FBRs" (Birraux 1992). This debate, held under the auspices of the OPECST, took up the safety issue and examined the question of converting the plant into a research facility.

This project for conversion into a research facility went hand in hand with the creation of pluralist scientific commissions entrusted with the task of offering expert opinions, in 1992 and then again in 1996; they gave positive but unenthusiastic opinions on the utility of such a project.

During the 1990s, evaluation of Superphénix took place officially and openly within the public arena - no less than 10 official reports were published between 1990 and 1997. Whilst some of the issues had already been debated, the institutional framework of the discussions was radically new; the same was true of the official and public nature of the assessments. These official reports concerned the safety, viability and finality of Superphénix, all of which were interlinked. In 1996, the Cour des Comptes accounting authority produced an economic evaluation of Superphénix, which was considered to be a public expenditure item; having determined the real cost overruns compared to what had been forecast, it assessed future income and expenditure in accordance with several options of availability and of the date for cessation of operation (Cour des Comptes, 1996). It was no longer a case of using these costs to extrapolate them to an industrial fleet: the aim was simply to assess the cost to the community of running such a research installation, and of asking, in budgetary terms, the question of whether or not to continue its operation.

We will set aside the numerous events that took place in the public arena, punctuating the years during which Superphénix operated, and content ourselves with questioning the link between the criteria for assessing Superphénix and its conversion into a research facility.

From the 1980s to the beginning of the 1990s, the criteria for "technical/economic / safety" evaluation constituted a triptych which was difficult to hold together, due to the innovative nature of the project which led to cost overruns. Furthermore, the more the project for an industrial fleet faded away, the stricter the technology's objectives of economic competitiveness became – in a climate of controversy where the modalities of extrapolation between "industrial prototype" and production reactor were being debated. It was no longer possible to maintain all of the aspects of the triptych in the objectives for competitiveness.

We have made the following hypothesis: the choice of conversion into a research facility constituted a form of response to the question of evaluation. As the reactor's finality changed, so did the economic evaluation criteria: Superphénix no longer prefigured a future industrial fleet, but constituted an experimental installation in itself, which was set objectives of technically demonstrating the feasibility of certain experiments with implications that were of great importance at that time. It was an attempt to return to the criteria of the first period, i.e. to demonstrate the feasibility of certain experiments on fuel management and industrial electricity production, as shown by the discourse of certain project managers when the plant was closed. When the project for an industrial prototype is unable to satisfy the criteria of its evaluation, qualifying the installation as a research project confers upon it a more suitable framework. It was then assessed by the Cour des Comptes, from an accounting standpoint, as a public expenditure item, and no longer as an industrial installation whose purpose was to meet criteria of profitability and competitiveness in a near future.

The controversial evaluation criteria: from "technical success" to a broader assessment

At the time that Superphénix was shut down by order of the government in 1997, written arguments designed to defend the plant put forward the notion of a technical demonstration of industrial electricity production: operating time was compared not to total time, but to time without any "administrative blockages"; the situation of the definitive stoppage after a year (1996) of satisfactory operation was harrowing; upgrades were completed. This method of validating the technology on the basis of technical success was in fact a legacy from the first period of our chronology, where the discourses on the opportunity offered by fast-breeder technology converged. During the second period, the evaluation criteria based on safety and affordability were more ambitious, whilst at the same time the need for the technology was fading. In the third period, it was first and foremost a question, in practice, of developing an industrial demonstration that integrated the three dimensions mentioned above. The prototype's change in status, to that of "research tool", then changed the way the entire economy of the project was viewed.

As evaluation has proven to be a key point for the analysis, we will discuss certain aspects of this result: what is assessed? Using what modalities? The answers to these questions vary, depending on the three periods we have set out.

The first important observation is that there was a permanent shift from prototype assessment to technology assessment. At the start of the innovation process, prototype development was born of an enthusiastic vision of technology: the promise of energy autonomy through fast-breeder technology is a graphic example (Le Renard, 2015). Whilst the prototype (Phénix for example) was deemed a success, extrapolation was unanimous and immediate: the prototype confirmed the original vision, i.e. the promising nature of the technology.

Yet when the prototype was weighed down with cost overruns and technical problems, it was open to controversy. Subjecting the technology to technical and economic testing by developing Superphénix only provided partial answers to its feasibility, so each event was interpreted in opposing fashions, depending on individual points of view.

On the one hand, the project leaders singled out negative events by relating them to the installation itself, in order for the potential of the future fast-breeder technology to be fully preserved. They underlined the fact that sodium leaks or air entries relate not to fast neutronics (applicable to FBR-technology as a whole) but to conventional engineering: cost overruns and other sundry issues were described as "teething troubles", as having nothing to do with the core technology and as being specific to a given plant. These discourses built a technology assessment based on the original vision and rejected the prototype tests as non-significant. They described the prototype itself as an exception to the technology that it was supposed to prefigure: they made the prototype even further removed from the technology, whilst at the same time confirming that the prototype (and fuel-breeding technology in general) was a useful first step.

However, the significance of these same events was viewed in a fundamentally different manner by outside actors taking an evaluation stance. Far from minimizing engineering issues compared to neutronics issues, academic economists and certain critical experts gave significance to the negative events: in their opinion, the cost overruns and technical problems affecting the prototype were positive proof of the technology's non-viability. Given that the prototype was intimately linked to the technology, they felt that the prototype had to be abandoned.

The shift in evaluation focus (economic in particular) from the prototype to the industrial technology was a form of extrapolation. Its criteria - such as the ratio used to predict the cost of investing in a mass-produced reactor as opposed to a prototype – were controversial. In the 1990s in France, the debate took place in open arenas, allowing conflicting arguments to be heard(4).

Let us take a closer look at this controversy: the actors disagreed on both the evaluation results and the nature of the criteria, the latter relating to different frames of reference and hence having permanently diverging evaluations. This was especially clear with regard to safety, with a risk-centred public controversy running alongside an institutional process of inquiry which had official sanction and which was designed to establish the safety of the plant. On another level, when it was a question of qualifying the technical demonstration carried out by the "industrial prototype", the actors involved in the controversy implicitly referred to different evaluation criteria: on the one hand, "technical success" supposed an R&D framework, whilst on the other, a pre-industrial dimension meant that several criteria had

(4) In the United Kingdom, the technical issues that arose during prototype development in the 1970s led to a debate involving similar arguments (Flowers, 1976).

to be combined: technique, safety and affordability. Ambiguity remained, even in official frames, whence the need for numerous reports to explain and then prioritise the criteria and components of the case file to be assessed.

In light of this, the process for evaluating a prototype might be facilitated by the question implicit in its technical characteristics, through explanation or de-scription. The design choices for an industrial prototype incorporate certain questions that the prototype must answer, certain elements that it must prove, all of which constitute implicit "specifications" that give it meaning.

By deconstructing the mission assigned to a prototype, and its possible ambiguity, one can gain a better understanding of the debates and controversies that surround it, and, in the case of a prototype project, even anticipate them. It is always useful to ask what a demonstrator must demonstrate. Is it a case of initial technical feasibility, as part of exploratory research? Or is one in a pre-industrial context where technical, safety and affordability issues will be combined with foresight elements? The "severity" of a prototype's evaluation evolves in accordance with the vision of the technology's future and needs: if the necessity is shared, a prototype's technical problems and cost overruns are acceptable. But if the industrial technology is only necessary hypothetically and over the long term, the evaluation criteria become more strict.

Finally, the revocable nature of these visions of the future encounters the inertias created by the long temporality of such a project. During the lengthy period of developing successive prototypes, the question of technical demonstration and guaranteed safety came to include commercial, European, economic and research aspects which had to satisfy assessments that went far beyond the notion of "proof of satisfactory technical operation". An explanation and interrogation of the implicit specifications upon which prototypes are defined and then assessed, along with their robustness over time, are required.

References

BARTHE (Y.), Le Pouvoir d'indécision. La mise en politique des déchets nucléaires (Paris: Economica, 2006).

BARTHE (Y.). Framing nuclear waste as a political issue in France. Journal of Risk Research, 12(7-8), 941-954 (2009).

BÉRIOT (L.) & VILLENEUVE (C.), Europe 1 & Antenne 2 présentent: Le surrégénérateur, l'enjeu nucléaire de demain (Palaiseau, FR: Sofedir, 1980).

BIRRAUX (C.) OPECST, Le contrôle de la sûreté et de la sécurité des installations nucléaires - Compte rendu des auditions du 19 mai 1992 sur l'éventualité du redémarrage de Superphénix et l'avenir des réacteurs à neutrons rapides, reports 399 (Senate) and 2765 (National Assembly), 10 June 1992.

BRUGIDOU (M.), & JOBERT (A.), "Le Débat sur l'énergie a-t-il lieu(x)? Une perspective topologique" in CIHUELO (J.), JOBERT (A.) & GRANDCLÉMENT (C.) (eds.), Énergie et transformations sociales: enquêtes sur les interfaces énergétiques (Paris: Lavoisier, 2015).

COUR DES COMPTES, "Rapport public annuel au Président de la République", Paris, 1996.

DURET, (M.), MARTIN (S.), LATOUR (B.), BISCHOF (H.), REYSE (S.), SONDERMANN (K.), OROBEN-GOA (A.), BIJKER (W.), HOMMELS (A.), PETERS (P.), LAREDO (P.), WOOLGAR (S.), MCNALLY (R.) & JANSSENS DE BISTHOVEN (O), "PROTEE - Procédures dans les transports d'évaluation et de suivi des innovations considérées comme des expérimentations collectives", Final Report for Publication. (Brussels, Belgium: European Commission, March 2000). Available on http://www.bruno-latour.fr/sites/default/files/PROTEE%20FINAL.pdf

FINON (D.), "Fast breeder reactors: the end of a myth?", Energy Policy, 10(4), pp. 305-32, 1982.

FINON (D.), L'échec des surgénérateurs: Autopsie d'un grand programme (Grenoble: Presses Universitaires de Grenoble, 1989).

FLOWERS (B.), Nuclear Power and the Environnement, Royal Commission on Environmental Pollution (RCEP), report. (London: HMSO, 1976).

FOASSO (C.), Atomes sous surveillance: Une histoire de la sûreté nucléaire en France (Brussels: Peter Lang, 2012).

HECHT (G.), The Radiance of France: Nuclear Power and National Identity after World War II (Boston, MA: MIT Press, 1998).

JOBERT (A.) & LE RENARD (C.), "Framing Prototypes: The fast breeder reactor in France (1950s-1990s)", Science & Technology Studies, 27(2), 2014.

LATOUR (B.), Aramis, or the Love of Technology. (Cambridge, MA: Harvard University Press, 1996).

LE MONDE, "M. Giscard d'Estaing réaffirme l'intérêt que porte la France aux surrégénérateurs", Le Monde, 19 January 1980.

LE RENARD (C.), "Le Prototype, à l'interface entre une promesse technologique et son industrialisation" in CIHUELO (J.), JOBERT (A.) & GRANDCLÉMENT (C.) (eds.), Énergie et transformations sociales: enquêtes sur les interfaces énergétiques (Paris: Lavoisier, 2015).

LEHTONEN (M.) & LIEU (J.), "The rise and fall of the fast breeder reactor technology in the UK: between engineering "dreams" and economic "realities"?". Project Report. University of Sussex, SPRU. (Falmer, Brighton: SPRU Reports and working papers, 2011). http://sro.sussex.ac.uk/53500/

OLIVIER de SARDAN (J.P.), "La Politique du terrain. Sur la production des données en anthropologie", Archives de la revue Enquête, 1, pp. 71-109, 1995.

PROST (A.), Douze leçons sur l'histoire (Paris: Seuil, 1996).

QUILÈS (P.), "Rapport d'information sur la politique de l'énergie", Journal Officiel de l'Assemblée Nationale, 405, 1 October 1981.

RIP (A.) & KEMP (R.), "Technological Change" in RAYNER (S.) & MALONE (E.L.) (eds.), Human Choice and Climate Change, vol. 2, pp. 327-399 (Columbus, OH: Battelle Press, 1998.)

SAUVAGE (J.F.), "Prototype and industrial SFRs: yesterday, today and tomorrow". Proceedings of IAEA "FR13" conference, March 2013. (Vienna: IAEA, 2013).
http://www-pub.iaea.org/MTCD/Publications/PDF/AdditionalVolumes/Pub1665Vol2Web.pdf

VENDRYÈS (G.), Superphénix, pourquoi? (Paris, NucléoN, 1997).