Power and Operations. Simondon and the Imaginaries of the Nuclear Industry

Potencia y operaciones. Simondon y el imaginario de la industria nuclear

Ange Pottin*

* École Normale Supérieure, Paris, Francia. E-mail: pottin@clipper.ens.psl.eu

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Abstract: In this paper, I use a theoretical framework inspired by Simondon to analyze the *closed fuel cycle* strategy implemented by the French nuclear industry in the 1970's. I confront the technocratic conception of technical ensembles, which sees them as the instantiation of a *power* over nature, with their technological understanding as systems of *operations*, i.e., points of mediation between technical invention and the natural environment. I argue that the *closed fuel cycle* strategy can be understood as relying on an imaginary ecology. I propose here a form of critical epistemology, which I compare with Jasanoff's theory of sociotechnical imaginaries, leading to a sociopolitical comprehension of the social efficiency and motives of such a representation. Finally, I question the complementarity conditions between those two frameworks, one normative and the other explanatory.

Keywords: Closed fuel cycle, philosophy of technology, nuclear industry.

Resumen: en este artículo, analizo la política del «ciclo de combustible cerrado» aplicada por la industria nuclear francesa en los años 70 utilizando un marco teórico inspirado en Simondon. Contrasto la concepción tecnocrática de los conjuntos técnicos como la instanciación de un *poder* sobre la naturaleza, con la comprensión por parte de los técnicos de los sistemas de *operaciones*, es decir, puntos de mediación entre la invención técnica y el entorno natural. Sostengo que la política francesa del «ciclo del combustible cerrado» puede entenderse como apoyada en una ecología imaginaria. Para ello, propongo un enfoque de epistemología crítica, contrastada con la teoría de los imaginarios sociotécnicos de Jasanoff, que permite dar cuenta de la eficacia y las motivaciones sociales y políticas de dicha representación. Por último, cuestiono las condiciones de complementariedad entre estos dos modos de análisis, uno normativo y otro explicativo.

Palabras clave: ciclo de combustible cerrado, filosofía de la tecnología, industria nuclear.

INTRODUCTION

In France, most residues produced by the nuclear industry are not considered "waste" but "materials" that can be recovered[1]. Irradiated nuclear fuel contains about 1 % fissile plutonium and 95 % nonfissile uranium-238 that can be converted into plutonium. There is, however, an important gap between the physical possibility and the technical possibility: in fact, only 5 to 10 % of these irradiated materials are reused once. The facilities responsible for extracting these radioactive residues, among which the La Hague plant stands out, are controversial: they are claimed to be polluting, costly, and dangerous, and their utility has been questioned[2]. Despite this, the French industry (particularly Orano, the CEA, and EDF) continues to promote this "closed fuel cycle" strategy as the best way to responsibly manage, through energy recovery, these toxic industrial residues.

What representation of technique is at work in this imaginary ecology? I will first try to propose an answer based on Gilbert Simondon's philosophy of technology. In his book entitled *Du mode d'existence des objets techniques* (henceforth MEOT), Simondon (2012) posits a distinction between two modes of representation of technical ensembles: (i) the technocratic conception, which sees technical ensembles as the instantiation of a *power* over nature (which can be evaluated according to its external results), and (ii) the conception of technicians, who understand the *operations* that comprise such technical ensembles through their intrinsic regulatory relationships. I will look for a technical representation in the literature on nuclear safety to oppose the technocratic claims of the promoters of the "closed cycle" by exposing the technical constraints behind the irradiated material processing network. In so doing, I intend to redeem a gesture of critical epistemology that the field of Science and Technology Studies (STS) has come to regard with a certain amount of mistrust. Indeed, epistemology has frequently relied on overly clear dichotomies between, on the one hand, the rational content of theories and innovations and, on the other hand, the supposedly irrational

[1] In Article L. 542-1 of the French Environmental Code, a "radioactive material" is defined as a substance for which a subsequent use is planned or intended (where applicable) after processing. This term includes irradiated fuel, plutonium, and depleted uranium.

[2] This issue was raised several times during the 2019 public debate on the French National Plan for the Management of Radioactive Materials and Waste (abbreviated PNGMDR in French) and has long been addressed in counter-expertise studies conducted by numerous associations (notably *Groupement des Scientifiques pour l'Information sur l'Energie Nucléaire*, Global Chance, Greenpeace, and *Réseau Sortir du Nucléaire*).

historical and social context in which they were developed. Yet, as most STS analyses reveal, the two are, on the contrary, often deeply linked.

In the case that interests us here, the survival of such an imaginary ecology would be incomprehensible if it were not for the fact that there are sociopolitical issues at stake, such as the unification of the French industry around common goals or its stand regarding accusations of poor waste management. To shed light on this technopolitical aspect, I will call upon Sheila Jasanoff's theory of sociotechnical imaginaries, which leads me to the following question: under what conditions can the normative approach of the epistemology of technology and the descriptive and explanatory approach of STS be compatible?

A Simondonian framework of analysis

The MEOT, first published in 1958, has been rediscovered quite recently (Simondon, 2014)[3]. Simondon's effort to deploy a renewed ontology of technology—a key aspect in his "new encyclopedism"—has been praised by various scholars (Barthélémy, 2008, 2014; Bontems, 2016; Chateau, 2008; Guchet, 2010)[4]. experts in STS see this theory as a precious source to understand the social entanglements of technical objects, insofar as they are considered by Simondon a support and a symbol of the "transindividual" (Latour, 2012; Stengers, 2004)[5]. This determination of technical objects has a critical side on which I will particularly focus here. The theory proposed in the MEOT seeks to liberate technical objects from inadequate modes of representation, whose survival and mutation within the post-war society is understood by Simondon as the main vector of technological alienation. This alienation is defined as residing in a rupture between, on the one hand, the technicality of the object, for which Simondon (2012) provides certain identification criteria, and, on the other hand, the representations through which one enters in a relation of use with that object[6]. These alienating representations

[3] In the last decade, Presses Universitaires de France has made a sustained effort to publish Simondon's other texts (including articles, courses, and conferences). For the philosophy of technology, see Simondon (2014).

[4] These authors have played an important role in this rediscovery of Simondon's oeuvre in France. See also the publications in *Cahiers Simondon*.

[5] A notion that has called the attention of Latour (2012) or, from a more critical stance, of Stengers (2004).

[6] In the MEOT, Simondon defines technical alienation in several different ways. Although its most fundamental form lies in the "psycho-physiological" domain, where use is based on a misconception of functioning that corrupts the "coupling" of the object–technician system, it is also defined ontologically as a rupture between the existence of the object in use and its ontogenesis.

are maintained through the organization of the technical activity, and we find, in Simondon's idea, the lineaments of an original criticism of industrial capitalism.

My aim here is not to present a systematic exposé of Simondon's theory but to formulate a framework of analysis using some of the conceptual tools it provides. The core of this proposal could be summarized as follows: Simondon (2012) offers us the theoretical tools to substitute a technological understanding of the *operations* in which human technical invention concretizes points of mediation with the natural environment for a technocratic vision of technical objects as places of instantiation of a *power* over nature.

Function and functioning

To understand this theory, one must consider a key distinction in Simondon's philosophy of technology: the individuality of technical objects does not lie in their function (i.e., their external purpose) but in their functioning (i.e., their internal operation). A function-based identification is superficial insofar as objects of different nature can serve the same purpose (a hydroelectric turbine and a photovoltaic panel supply electricity), while those with very similar structures can have different uses (a pressurized water nuclear reactor can produce electrogenic energy or propel a submarine). Function, on the one hand, derives from a requirement that is heterogeneous to the proper order of the technical reality and is informed by social and economic factors. Functioning, on the other hand, is the result of a process of individuation specific to technical objects, which Simondon refers to as "concretization". This individuation is marked by moments of structural reconfiguration—acts of invention—, which help to solve problems by bringing greater coherence between the elements and the "associated environment". The machine—a concept that Simondon reformulates as a partially self-regulated "technical individual"—is a metastable moment of a lineage, whose intrinsic configuration (the causal system of functioning) can be understood in terms of the problems it has solved. Thus, the distinction between function and functioning, along with the theory of concretization, allows for an identification of the right zone of technicality.

The technocrat and the technician

The critical side of the MEOT, as well as the most complete exposition of Simondon's theory of alienation, is found in its second part (entitled *Man and the technical given*). Here, I will mainly focus on Simondon's critique of what he calls "technocratic philosophy", which he claims is rooted in a certain way of relating no longer to individuals but to technical ensembles. An ensemble designates the superior level of the technical reality, where different individuals are placed in a relation of regulation without being integrated within a new self-regulated individual. An example of this could be a nuclear power plant grouping together individuals like reactors, turbines, and cooling pumps. The term, however, can also refer to broader realities, such as an electricity distribution network.

The understanding of ensembles entails an opposition that can be summarized in two figures: the technician and the industrial organizer[7]. The technician is in charge of the regulations between technical individuals. The concept of regulation—borrowed by Simondon from cybernetics (Guchet, 2010)[8] —designates information insofar as it contributes to ensuring the metastability of a system through exchanges between its different elements. During adjustment, the technician interprets the information provided by the machines and regulates their functioning in relation to it. He, thus, takes charge of the relations of interconnection that are intrinsic to technical ensembles. Conversely, the industrial organizer conceives of the ensembles in terms of their external purpose. His point of view is doubly abstract: on the one hand, his representation is mediated by quantified economic (profitability) or energetic (efficiency) evaluations and, on the other hand, he only grasps the ensembles after they have been operating (at the time of the result) and is, therefore, "behind" the technicality in its own mode of existence. His perspective of the finalism of technology is then alienated:

> … the industrialist, like the worker, is driven by the finality: he aims at the result; their alienation lies in this. The technician is the man of the operation under way; he assumes, rather than the direction, the self-regulation of the ensemble in operation (Simondon, 2012, p. 176).

[7] The relation to machines embraces a third figure: the worker. Nonetheless, this one is, in the industrial organization of the technical activity as Simondon analyzes it, confined to a relation to technical individuals.

[8] In particular from that of Norbert Wiener, of whom Simondon was an assiduous reader and one of the introducers of cybernetics in France. For a thorough analysis of Simondon's complex relationship with cybernetics, see Guchet (2010).

This alienated representation of the organizer provides the point of view that gives rise to what Simondon calls, in the continuation of this passage, the "autocratic philosophy of techniques" and the "technocratic philosophy"[9]. Rather than a fabric of technical individuals in a relation of interconnection, such conceptions consider technical ensembles a place where machines are used to obtain power, final aim is the conquest of nature, the domestication of natural forces by means of a first enslavement, as a tool for a "conquering aggression" characterized by a rape of nature (Simondon, 2012, p. 176). Instead of a relation of equality, where the technician is the partner of the machines, this technocratic conception establishes a relation of domination. Simondon, thus, provides a less sociological than epistemological characterization of technocracy: it is not fundamentally characterized as a position in a given class but as a certain type of alienated relation to technical objects, i.e., an enslaving relation. This enslavement, besides having social consequences, as the machine becomes a "slave that is used to make other slaves" (Simondon, 2012, p. 176), also brings ecological consequences.

The operation as mediation against the power over nature

The critique of technocratic philosophy takes up a motif that provides the backbone of the MEOT: the representation of finalism of technical objects is alienating insofar as it masks the authentic locus of technicality. In the conclusion part of the book, this locus is redefined as consisting of *operations*. Simondon intends to substitute —to the hylemorphist ontology which understands the technical activity as imposition of form to an inert matter—, an ontological determination of the technical objects as systems of operations where form and matter exist at the same level within a "stable mixture of human and natural". It is this mediation, this mixture of technical invention and nature, that is obscured by the technocratic conception, which sees technical ensembles as the instantiation of a power over nature. The obscurity of the operation has become, with industrialization, the obscurity of the machine: "man knows what goes into the machine and what

[9] Each term covers different realities: the "autocratic" philosophy implicitly refers to a conception of technology in vogue in Nazi Germany in the wake of authors such as Oswald Spengler, while the "technocratic" philosophy explicitly alludes to Saint-Simonianism and its expansion in the French Second Empire. If, for obvious political reasons, one cannot completely identify these two notions (I thank one of the reviewers of my article for having drawn my attention to this point), they share a common background in their approach to technical ensembles as the instantiation of a power over nature. This explains the general term "technocratic" conception of technical ensembles that I am using here.

comes out of it but not what is done in it", and "to command is still to remain external to what one commands" (Simondon, 2012, p. 338)[10].

Beyond the relation to technical objects, the ecological relation between human activity and the natural environment is biased in the technocratic conception of the industrial organizer. This leads to a paradox: while technical ensembles are praised as vectors of human power over nature, they also mask the conditions of possibility. This is perhaps the main point to keep in mind in the case that follows, which concerns the valorization of residues from the nuclear industry.

Case analysis: "*surgénération*" and the "nuclear fuel cycle"

In the 1970s, France embarked on a massive nuclear power building plan, which led to the construction of most of the 58 reactors that are currently in operation[11]. This major program—motivated in the medium term by a desire to ensure the "security of supply" of the French energy —is inscribed by some of its promoters in a long-term horizon known at the time as "*surgénération*"[12]. This term designates a technical system based on two pillars: (i) reprocessing, i.e., the recovery of recoverable materials (about 1 % fissile plutonium and 95 % uranium that can be converted into plutonium)[13] from the irradiated fuel from reactors, which has been carried out at La Hague since 1966; and (ii) Fast-neutron Breeder Reactors (FBR), which make it possible to obtain a better rate of conversion of uranium into plutonium up to the point of eventually "overgenerating" (*surgénérer*) fuel by producing more fissile material than they consume. These reactors, however, will only ever exist as a prototype. This system was supposed to open up the

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[10] In this alienation, the worker and the organizer are turned back to back. Or, more precisely: the enslaving relation to the ensembles of the organizer leads to both an enslaving and enslaved relation of the workers to the individuals.

[11] It should be remembered that France is by far the most nuclear-powered country in the world, generating approximately 75 % of its electricity from nuclear sources. By comparison, the United States, which has more power plants in terms of installed capacity, generates only 20 % of its electricity from nuclear sources. Other highly nuclear-powered industrial powers such as South Korea (25 %), the United Kingdom (18 %), Germany (18 %), and Japan before the Fukushima disaster (25 %) have similar percentages.

[12] The English word for it is "breeding". However, I prefer to keep the French term as it was used by its actors, which could be translated as "overgenerating" because it more directly conveys the imaginary that I am analyzing. The term "*surrégénération*" was also used until the 1980s.

[13] To fully understand this point, we must add an important fact about uranium. In its natural state, uranium consists of two isotopes: U235, which is fissile but only present in deposits at a level of 0.7 %; and U238 (the remaining 99.3 %), which is not fissile but can be converted into fissile plutonium-239 after the absorption of a neutron emitted during the fission of another atom.

possibility of both total energy independence (fuel being obtained from French industrial facilities) and a near-perfect management of residues (the majority being recovered energetically). Although this great project ended mostly in failure, it continues to provide a horizon and a tool for legitimizing the nuclear power industry[14].

My argument is as follows: "*surgénération*" does not designate a technical operation but a technocratic power; therefore, the discourses on *surgénération* offer a distorted representation of the technical reality of the irradiated material processing network. Firstly, *surgénération* designates an energetic and economic function rather than a technical operation. Secondly, the discourse on *surgénération*, centered on the production of new energy materials in FBRs, minimizes the constraints specific to the regulatory relations that govern the technical ensemble formed by the irradiated material treatment network. Finally, I will argue that the discourses on FBRs and on the fuel cycle are based on an imaginary ecology that provides a distorted representation of the relations between the nuclear industrial activity and its environment.

Surgénération is not a technical operation

FBRs were established in the 1960s as the keystone of the *surgénération* system: only they are able to complete the "fuel cycle" by making the best use of the recovered plutonium and uranium-238. This has to do with their functioning, which must be understood in relation to that of other nuclear reactors. In these reactors, generating a chain reaction based on uranium or enriched uranium fuel requires the use of a moderating element, which maximizes the chances of fission by "slowing down" the neutrons. In most French reactors launched in the 1970s, this element is pressurized water. Nevertheless, the moderator will also capture part of the neutrons emitted by fission and minimize the absorption of neutrons by uranium-238 and, thus, the quantity of plutonium-239 that is formed. FBRs must, therefore, respond to the following technical problem: generating fission without a moderator. Most nuclear-powered countries, including France, have opted to use (i) liquid sodium as a coolant, which allows the energy emitted by fission to be transferred without practically capturing neutrons, and (ii) a plutonium-based fuel, which, besides being more fissile than uranium, makes it possible to

[14] For example, Orano's (s.f.) communications still mention the "96 % recyclability" of irradiated fuel. As for the CEA (2015), it continues to project the deployment of a fleet consisting of 50 % FBRs by 2050.

do so without the use of a moderator. This creates a supply constraint: in order to produce plutonium in interesting quantities, a plutonium stock is required. From a Simondonian point of view, FBRs are, then, technical individuals who bring together three elements (plutonium-based fuel, liquid sodium, and "fertile blankets" of uranium-238), whose genesis can be traced back to the resolution of a parasitic absorption problem that occurs in reactors with "thermal neutrons"[15].

Nonetheless, these reactors were, at least during the 1970s, much more often designated by their *surgénérateur* potential rather than by their technical functioning. This primacy of function over operation may seem quite normal from a sociological perspective, in that it is, above all, a matter of motivating substantial investments (we will come back to this later). However, the point I want to raise here is that the discourses on FBRs are not strictly speaking technical in a Simondonian sense. In fact, the presentations of *surgénération* frequently use an energetic and economic register. Let us illustrate this with a few examples:

> The essential advantage of these *surrégénérateurs* is that they consume not only the part of U235 contained in natural U but also most U238. Hence, under these conditions, one ton of natural U may be equal to more than 500,000 tons [...] of coal (Commission Consultative pour la Production d'Électricité d'Origine Nucléaire [PEON], 1964).

> The first effect of *surgénération* is, of course, to considerably increase the amount of energy resources that can be extracted from uranium, either because of its better intrinsic use or because of the indirect effect of a reduced economic impact of natural uranium on the final cost of electricity. This reduction allows for the exploitation of much poorer deposits, thus increasing the number of available reserves (PEON, 1970).

> Ultimately, this means that all uranium, U235 and U238 combined, may be used as fuel, thereby increasing our fuel supply at least 100 times. Let us translate this into financial terms: if we use a ton of natural uranium that is 100 times better, we can pay 100 times more for it at the same cost of use (Bienvenu, 1999).

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[15] The world's first nuclear power reactor (EBR-I), which went into operation in Chicago in 1951, was a fast neutron reactor. However, subsequent liquid sodium reactors (in France, starting with Rapsodie, the first prototype that began operation in 1967 on the CEA site at Cadarache) were designed with slow neutron reactors in mind and to address the sub-optimal fuel use problem that occurs in such reactors.

The first two quotations were taken from reports by the PEON commission (PEON, 1964, 1970), an advisory body that played an important role in promoting nuclear power in France from the 1950s to the 1980s; and the third one, from the memoirs of a nuclear engineer (Bienvenu, 1999). They all share one thing: they do not allude to the reactor or the technical unit on which it depends but to the energy resources it is supposed to generate. From this energy register, one can easily move to an economic register: the impact on the cost of electricity and on the market for raw materials. In other words, in these discourses, "*surgénération*" designates a power of valorization rather than a technical operation instantiated in a particular individual. Let us clarify this argument. The functioning of a FBR responds to a local technical problem of parasitic neutron absorption and low yield of fissile material due to the use of a moderator. *Surgénération*, nevertheless, goes beyond this technical problem encountered in the reactor to designate an energetic and economic power of increasing the available resources. The reactor, thus, appears as a machine with a power that directly affects the natural environment from which the industry extracts its raw materials. Not only the operation but also the technical ensemble disappears.

The "fuel cycle" between the power to generate energy materials and a fragile technical ensemble

FBRs are not the only technical individuals in operation. The supply of plutonium necessary to feed them and the recovery of the plutonium they produce depend on a large ensemble of technical individuals, with reprocessing facilities being the main ones. Reprocessing—a technique of military origin[16]—involves treating irradiated fuel from reactors in order to separate the radioelements that can be recovered from the other "fission products"[17] by means of a series of chemical operations. For instance, reprocessing plants at La Hague[18] are based on the

[16] The first reprocessing plant was the American Hanford plant, which was built as part of the Manhattan Project and from which the plutonium for the bomb that destroyed Nagasaki was extracted. The USSR put a similar plant into operation in 1949 at Maïak. For further information on these two plants, see Kate Brown's formidable historical investigation (Brown, 2015), which focuses on the work and living conditions of the workers in these plants. France started to produce military plutonium at the CEA site in Marcoule in 1958.

[17] The term "fission products" includes a large number of unusable radioelements that account for about 4 % of the irradiated fuel. Some of these elements, like plutonium, are extremely radioactive over very long periods (e.g., americium and curium) and tend, as we shall see, to be present almost everywhere.

[18] The La Hague site was initially operated by the CEA and then by Cogéma (a fuel cycle subsidiary of the CEA under private law) in 1976. Its operation was handed over to Areva in 2000, and it is currently run by Orano.

PUREX process, which uses tributyl phosphate (TBP). Beyond reprocessing, a whole range of operations are mobilized within a technical ensemble, including intermediate pool storage, transportation, waste packaging, filtration, and fuel fabrication. There is, therefore, a distorting effect in speaking of *surgénérateur* reactors: it summarizes, in one point of space and time, a series of operations that are distributed over a vast whole, which can be referred to as the "irradiated material treatment network"[19]. In my opinion, one may argue that the industry has been a victim of its own distorted vision. The plan of the 1970s was founded on the idea of an energy material that could be obtained directly from industrial production and just required the arrival of FBRs to be fully utilized. As stated in a report by the PEON commission: at this stage, the primary energy resource will no longer be linked to a geographical distribution, as it is today, but will appear as a simple by-product of industrial activity (PEON, 1973). This idea of availability has found institutional expression in the decision to count plutonium (the fuel for FBRs) as being at zero cost[20]. The point is that, as we shall see, the technical implementation of the network for processing irradiated material will greatly weaken this idea.

From a Simondonian perspective, this can be summarized as follows: the promoters of the nuclear industry are in the position of organizers of a technical ensemble. They consider it from the point of view of its expected result, i.e., its energetic potential (to provide the fuel of the future) and economic potential (to position France on the fuel market). As a result, they ignore ensembles, collections of interconnected technical individuals, whose regulatory relations are handled by technicians. To find the expression of such a technical point of view, one can look at nuclear safety. Its role is to ensure the proper functioning of facilities and guarantee that the risks they pose are maintained at acceptable levels[21]. In the 1970s, some French safety engineers were responsible for conducting technical investigations of the "cycle's" facilities, most of which had never operated on such a large industrial scale. Their mode of investigation is based on the paradigm

[19] I propose this name because it allows us to move away from the term "fuel cycle", which carries the imaginary ecology of the industry. Some experts have proposed the term "fuel chain" for the same purpose.

[20] For further details on this point, see the work of Finon (1982, 1989), an expert economist who devoted part of his life to criticizing breeder reactors.

[21] This activity of expertise has a political dimension that we will examine later. We will question the limits of identifying nuclear safety engineers with the ideal figure of the Simondonian technician in the following section.

of the “barrier method”: its goal is to ensure the installation of a series of devices (independent of one another) to maintain a barrier between the radioactive substances and the public (Roger, 2020; Foasso, 2003)[22]. This method offers an access to the ensembles, which focuses on the systemic relations between the different elements of the facilities under consideration, i.e., what Simondon, after cyberneticians, means by “regulations”.

These facilities must, after all, deal with the properties of an exceptional material. The irradiated residue will require technical precautions to be implemented, which will weaken the idea of FBRs carrying alone the power to generate energy materials. I will focus on two cases: cooling and criticality safety.

Irradiated fuel assemblies contain fission products, some of which are highly radioactive and continue to emit energy in the form of heat. This “release of residual power” constitutes one of the central technical problems regarding the safety of the “cycle”. From a Simondonian point of view, it represents a technical constraint that may call into question the stability of the ensembles. It also illustrates the technical perspective of safety in its tension with technocratic aims: the energy potential of the fuel becomes a risk to be contained. The French nuclear industry opted for a strategy of pool storage (Lefort & Puit, 1979)[23]: the irradiated fuel was first stored at the site of the power plant for a minimum of three months, so that it could be transported under acceptable safety conditions. Then, upon its arrival at the reprocessing plant, it was stored again for a period that, in the 1970s, was set at three years (a term considered by the operator himself to minimally ensure the proper functioning of the plant’s operations) (Leclerc et al., 1979). The properties of the material, thus, impose constraints on the setting of minimum cooling times, which undermine the idea that the *surgénération* of spent fuel in FBRs would allow for its immediate recovery. This idea is reflected, for example, in the following statement delivered by Besse et al. (1977):

[22] For a sociological and epistemological analysis of the technological paradigm of the barrier method, see Roger (2020), who focuses on the case of seismic safety margins in power plants. For a detailed history of nuclear safety in France, see Foasso (2003).

[23] This strategy is described in a report (Lefort & Puit, 1979). The reports by the Département de la Sécurité Nucléaire (the French Department of Nuclear Safety)—created in 1976 at the CEA—to which I refer here are available for consultation in the archives of the Institute of Radioprotection and Nuclear Safety at the Fontenay-aux-Roses site.

> The construction of SuperPhénix[24] will provide us with the elements necessary for the launching of a first series of large fast breeder plants. The rate at which these are to be commissioned will logically be based on the immediate use of plutonium produced by slow neutron plants (p. 8).

Aside from the constraints related to cooling (which affect most industrial facilities), the handling of irradiated materials poses a more specific problem: the risk of criticality[25]. Plutonium and uranium-235 are highly unstable elements that, under certain conditions, can initiate chain reactions that could produce particularly deadly gamma radiation. Controlling the risk of criticality has, therefore, been the focus of important safety studies, which are summarized in a 1979 report by the French Department of Nuclear Safety (Leclerc & Puit, 1979). Its authors regard the industrial production of fissile materials as largely a constraint on the stability of facilities: hundreds (even thousands) of tons of fissile material (enriched uranium and plutonium) are used annually in the French industrial sector of the fuel cycle. Yet the handling of a few kilograms, without special precautions, could lead to a criticality accident (Leclerc & Puit, 1979).

Considering this constraint, it is impossible to adopt a "control by mass", i.e., a set of administrative procedures to limit the quantity present in the facilities (Leclerc & Puit, 1979)[26]. Hence, Leclerc and Puit (1979) advocate a "control by geometry", which is based on the enactment of norms concerning the dimensioning of the fissile material packages and of the facilities that will receive them. These standardization measures have proven to be more economical and compatible with the constraints of industrial production. Nevertheless, the authors note that the preventive measures taken, however perfect they may be, only make an uncontrolled divergence in a facility where the amount of fissile material is potentially supercritical very unlikely but not impossible. This admission of weakness is particularly linked to an epistemic problem: given the great variety of situations in which fissile materials are found throughout the "cycle", it is

[24] First high-power prototype reactor (1200 MW, while the previous French units—Rapsodie and Phénix—had a power of 60 and 250 MW, respectively) authorized for construction in 1974. Superphénix was initially designed to be an "industry leader", carrying all the promise of large-scale breeder reactors.

[25] The third group of risks are those related to the extreme radiotoxicity of plutonium: 1 milligram inhaled in the form of dust can cause leukemia. We will not, however, discuss them in this article.

[26] More precisely: accounting of fissile materials by means of input-output balances with a continuous display of the quantity present, special transfer rules, detection of possible accumulation with a cleaning procedure, and reset (Leclerc & Puit, 1979).

impossible to foresee all the potential points of fragility[27]. The problem faced by engineers is, therefore, a problem of complexity[28], and establishing *a priori* standards based on laboratory studies must give way to incident analyses that allow for the *a posteriori* identification of potential points of fragility.

As we can see, the constraints of irradiated material processing operations are reluctant to the materialization of a power to generate artificial energy materials in industrial production. Even more, the technocratic demands for results (efficiency and profitability) are in tension with the work recommended by safety technicians.

The imaginary ecology of the nuclear industry

This distorted representation of technical ensembles encompasses a misunderstanding of the relation between the activity of the nuclear industry and its environment. The power to generate energy materials intends to combine the long-term response to the objective of security of supply with the assurances of a near-complete control of radioactive residues. The goal is to promote a more responsible alternative than the competing "open fuel cycle" option, which treats irradiated fuel as waste to be stored (Couture, 1975)[29]. In an interview in 1977, André Giraud stated: "To refuse reprocessing is to choose to store irradiated fuel in astronomical quantities. […] Reprocessing is an ecological necessity". On this point again, the way safety engineers describe the operations of the irradiated material processing network allows us to see a distorted representation in these statements. They lead less to a limitation of the amount of waste than to a diffraction of the residues[30]. Reprocessing generates its own residues (which do not exist in the

[27] See Downer's (2019) general treatment of this issue. He employs methods from the philosophy of science to construct a notion of "epistemic accident".

[28] On the problem of complexity in nuclear and industrial safety, see Perrow's (1999) theory of "normal accidents".

[29] France is currently one of the last countries, along with Russia and India, to reprocess spent fuel at a large scale. Most other industries abandoned this practice, sometimes as early as the 1970s, mostly for economic reasons: the costs associated with the maintenance of reprocessing plants make them unprofitable. See Couture's paper (1975), which documents this issue from the point of view of the management of the CEA.

[30] Statements such as the one quoted above actually play on the distinction between ultimate "waste" (not usable, even theoretically) and recoverable material. From an administrative point of view, it is true that the amount of "waste" (i.e., what is counted as final waste) increases significantly in the "open cycle", whereas it is the number of *residues* that increases in the "closed cycle".

"open cycle"): chemical effluents charged with radioelements from reprocessing plants, pieces of fuel cladding, waste from filtering facilities, among others. These residues have specific storage facilities, which were defined in the 1970s (Leclerc et al., 1979)[31], and are considered a constraint on the cycle's operations insofar as most of them are poisoned by fission products. A portion of them is eventually released into the environment: at La Hague, the pipes of the *Station de Traitement des Effluents* (abbreviated STE in French) discharge effluents loaded with, for instance, tritium, cesium, and plutonium into the English Channel[32]. The fact is that all of these problematic interactions with the environment are invisible in the discourse that makes the "cycle" the place of a power to valorize irradiated fuel.

The technocratic representation of the irradiated material treatment network is, thus, the bearer of what I call an "imaginary ecology", which substitutes the representation of a fantasized power over matter for the real mediation relations between the industrial activity and the environment in which it is inscribed. However, if the Simondonian perspective allows us to bring this discrepancy to light, it leaves us somewhat baffled as to the interpretation of the political, social, and economic motivations that dictate its establishment and maintenance. Why is the French nuclear industry so keen on its imaginary ecology?

Understanding and criticizing imaginaries

Simondon's sociopolitical shortcomings

From the perspective of sociological analysis, the Simondonian theory suffers from a form of abstraction. It provides, through the worker-organizer-technician tripartition, a fixed and idealized model of the organization of the industry born in the 19th century. In practice, however, these three groups are rarely well distinguished. Organizers include technicians who are responsible for designing and building the ensembles that inscribe their power in physical facilities.

[31] Notably in the study by Leclerc et al. (1979), which defines, for UP2-800, devices for recovering hulls (pieces of undissolved fuel cladding), for storing fines (radioactive metallic impurities), for filtering gaseous releases, and for recycling liquid effluents. To this could be added the radioactive sludge from the effluent treatment plant.

[32] These effluents were the subject of campaigns by Greenpeace in the late 1990s. The issue of radioactive discharges from La Hague has encouraged the development of extensive studies in the field. For further information on this, see Barbier (2019). Finding documentation on the STE at La Hague, whose management has remained the fairly exclusive prerogative of Cogéma, is quite difficult.

Since the CEA had engineers who were properly trained in the technical constraints specific to nuclear energy, it was able to assert its policy, which involved the construction of plutonium plants, from the 1950s onwards (Hecht, 2014). Yet technicians hardly ever take on the disinterested role that the Simondonian analysis prescribes for them[33]. Nuclear safety engineers, whose investigations have been mentioned here, are not pure partners of the machines; they also play an organic role in maintaining the social and economic equilibrium of the industry (Foasso, 2003)[34]. Not only are they *de facto* stakeholders in industrial interests (whose material conditions of felicity they must ensure), but their practice also contributes to framing industrial risks in a way that makes them socially and politically acceptable[35, 36].

This idealized figure of the technician is tied to a deeper problem. For Simondon, it is the technique itself (once understood in its own constitutive principles) that provides the standard whereby a critique of social organization can be made. The issue is, therefore, to know which technical point of view provides this right representation of technique and, thus, to know who can act as arbitrator. This problem appears in a later text by Simondon, in which it is specifically addressed as a matter of nuclear technology[37]. With the problem of radioactive waste in mind, Simondon uses the nuclear fusion project as an example of a tendency of "deep technology" to recover the errors of "the technique", and, more generally, a tendency by which "one joins the ethics by the fundamental progress of technology" (Simondon, 2014, p. 340). Then, he confronts this "normativity immanent to the development of techniques" to the new normativity resulting from the ecological movement. Although he recognizes that some of its diagnoses are accurate, he denounces its "irrational" tendencies. In particular, he criticizes its paradoxical attitude towards nuclear energy, which ignores the

[33] In the author's own perspective, the figure of the technician takes on a normative rather than descriptive character.

[34] The accepted expression is "French-style technical dialogue". In this expression, the industry, rather than being subject to external control (as with the American safety agencies), regulates itself through *ad hoc* commissions where representatives of all parties sit down together. For more details on this, see Foasso (2003).

[35] For further information on this political dimension of technical expertise, see the sociopolitical conceptualization of Boudia and Jas (2007).

[36] We leave aside the issue of the position of nuclear workers here to ensure clarity and unity of purpose rather than because it is irrelevant.

[37] *Trois perspectives pour une réflexion sur l'éthique de la technique* published in Simondon (2014).

fact that controlled fusion could, as he claims, become an industrial reality after twenty years (Simondon, 2014). In this text, the norm of "deep technology" is confused, in a disturbing manner, with a rather classical legitimizing discourse of the nuclear industry. The point is that fusion is still today at the experimental stage. However, the distant perspective offered by this technical project continues to serve as an instrument to legitimize the industry, in the same way as the imaginary associated with FBRs, which it joins to provide a representation of a nuclear industry that offers a responsible management of its residues. Thus, the Simondonian perspective, which mobilizes an idealized norm of technical evolution, might be accompanied by a lack of critical distance from the discourses of certain technologists, which carry a technocratic dimension.

STS methods have been developed in part to counteract such misunderstandings. To the idealized norms of science and technology resulting from the constructions of epistemologists, their investigations intend to substitute a representation of science and technology in the process; to the figure of the scientist or the technician accessing the objective nature of things by virtue of his or her disinterestedness, they substitute an elucidation of the socio-political logics in which the work of scientific and technical communities is immersed. This descriptive approach has a critical dimension, in that it allows us to take a step back from the industry's self-presentation, legitimization, and mobilization discourses. I will now focus on an example of this type of approach.

Surgénération and Jasanoff's sociotechnical imaginaries

Among the many analytical frameworks that have been developed in STS, the sociotechnical imaginaries approach, formulated by historian Sheila Jasanoff, is one of the most effective to study cases like this (Joly, 2010; Le Renard, 2018)[38]. In a seminal article Jasanoff & Kim (2009) define sociotechnical imaginaries as collectively imagined forms of social life and social order reflected in the design and fulfillment of nation-specific scientific and/or technical projects. Imaginaries both describe and prescribe futures. They provide a level at which the construction of technology and that of politics are consubstantial: national goals shape future

[38] Indeed, current STS researchers tend to understand this case quite spontaneously in terms of imaginaries. Another gateway is the theory of the economics of sociotechnical promises developed by Joly (2010), which I have left aside to lighten the argument. For an analysis of overgeneration through the lens of the theory of the economics of promises, see Le Renard (2018).

technology by motivating investments and industrial strategies, as well as by including and excluding social groups. Conversely, the technical future, thus defined, shapes the nation, an entity that is always reimagined. To identify imaginaries, Jasanoff advocates a method based on transnational comparison, which she and Kim apply to a case study concerning, precisely, the American and South Korean nuclear industries.

At the end of the Second World War, the United States mobilized, in the management of its nuclear industry, an imaginary centered around the notion of *containment*. This notion defined the "atom" as a controllable and pacified entity. The country, in return, assumed the image of a responsible regulator of a technology that could always get out of control. This imaginary has been mobilized throughout the history of the American nuclear industry both at the level of international relations (by describing other nuclear-powered countries, particularly the USSR, as irresponsible powers) and at the national level (by providing a repertoire of legal norms to contain the fears concerning a loss of control over radioactivity).

The case of South Korea is different, in that the sociotechnical imaginary of the nuclear industry is articulated around the notion of *atoms for national development*. After the Japanese occupation and the separation of the two Koreas, South Korea intends to develop the atom to assure its national energy capacity and, thus, its independence. This issue will play a role in its relationship with the main exporting country: the United States. This imaginary will also be mobilized in national politics by providing a repertoire from which political frameworks of representation were formulated, at the time of its democratic transition in the 1980s, to include citizens in a national development program. This program was later criticized because of its antidemocratic management.

It is easy to see how this concept offers an interpretation frame for the case that interests us. *Surgénération* provides the technological keystone of the imaginary energy independence through which the French nuclear industry—public or semi-public companies (EDF and Cogéma), government agencies (CEA and safety), the government (ministries of industry and finance), and the private sector—motivated the massive investments it required, despite sometimes deep divisions. These investments, only profitable in the medium term, were going to offer a long-term alternative to importing raw materials that could suffocate the national economy[39]. This imaginary was matched by the ideology that intended to restore, through technical prowess, the international "*rayonnement*" (radiance) of a France recently dismantled from its colonial empire. In return, the nation is reimagined as an entity organized around a technologically advanced State that works for the public good by defining sustainable future perspectives. This imaginary of the *surgénerée* society also served as a repertoire of arguments to respond to critics. The energy independence symbolized by the hi-tech artificial infrastructures built on national territory made it possible to answer the accusations (especially from the United States) of playing the game of nuclear proliferation. Only a planned industry could assure that such a dangerous material was managed responsibly (IAEA, 1977)[40]. Likewise, to respond to the internal disputes surrounding the problem of waste (Topçu, 2013)[41], this industry allowed for an optimal management of toxic residues (which were to disappear when used for the energy independence program)[42], a management in line with ecological objectives.

The "radioactive matter" category included in the French Environmental Code in 2006 is currently a legal expression of this long-lived imaginary: it categorizes most industrial residues as likely to be used for energy recovery. At stake again is the maintenance of an imaginary energy independence, in which the industry is organized around the long-term goal of supplying (and, thus, of containing) an energy material available on national territory. The current difficulties faced by this program are also consistent with this interpretation. The abandonment of the ASTRID (the latest prototype of an FBR) project in 2019 is interpreted by certain actors, notably at the CEA site, as the result of a conflict between, on the one hand, the current policy of the government and the industry, which is defined in terms of short-term financial objectives, and, on the other hand, the State's planning role and its adherence to a public service ideology necessary for the success of such a

[39] A preliminary formulation of this imaginary can be found in the address of Francis Perrin, then High Commissioner for Atomic Energy, to the National Assembly in 1956 on the occasion of the vote that led to the creation of Euratom.

[40] On the basis of this argument, the French delegation defended its policy at the 1978 International Nuclear Fuel Cycle Evaluation. See also Giraud (1977).

[41] The first protest around nuclear waste in France took place in Saclay in 1972. It was notably relayed by the *Survivre et Vivre* newspaper. For an analysis of how these critiques were "governed", see Topçu (2013).

[42] In this imaginary, we find the canonical image of waste (employed, for instance, in the 1970s by President Valéry Giscard d'Estaing), which would fit entirely in an "Olympic swimming pool". This image was used again by Anne Lauvergeon when she was head of Areva in the 2000s.

project[43]. This is a sign, in the negative, of a link, within the same sociotechnical imaginary, between the "closed cycle" policy and the definition of the features of the nation-state in charge of it.

An analytical framework such as this one can, thus, account for the social and political dimensions of the imaginaries in which technical projects are immersed. It also makes it possible to deconstruct the idealized image that the communities in charge of these projects give of themselves. Yet this description obscures a key aspect of the Simondonian analysis that I proposed earlier: the gap between the imagined and technocratic representation of technique as a power over nature and the technical operations that it aims to mobilize. Of course, the illusory character of the sociotechnical imaginary is implicit in Jasanoff's analysis: although the "atom" as a mastered entity, for example, is indeed a form of symbolic reduction in relation to the series of facilities on which the nuclear industry is based, this is not made explicit. STS investigations often refuse to enter this field because they reject the normative approach of epistemology. However, it seems to me that we can certainly take the critique a step further and not only examine the social logics at work in the formation of imaginaries but also explicitly criticize their illusory nature with the help of a conceptual analysis.

CONCLUSION

How to analyze the imaginary? STS and epistemology of techniques

Is the analysis through sociotechnical imaginaries complementary to the Simondonian approach that we have proposed? The answer to this question requires an epistemological reflection, which can be centered around the notion of the imaginary. On the one hand, the Simondonian approach makes it possible to reveal the imaginary dimension of the discourses on "*surgénération*", i.e., to show that they are, at least partly, the result of a *cognitive illusion* maintained by the organization of the industry. On the other hand, Jasanoff's analysis allows us to demonstrate the active role of imagination in the definition of national industrial

[43] Yves Bréchet, a High Commissioner of the CEA who resigned, recently gave several press interviews on this subject. Visit, e.g., https://revue-progressistes.org/2019/09/22/larret-du-programme-astrid-une-etude-de-cas-de-disparition-de-letat-stratege/. I also interviewed young retirees from the CEA, which allowed me to confirm that this is a fairly common idea.

policies and, therefore, their *material effectiveness* in this same organization of the industry. These two dimensions coexist within the concept of the imaginary. We can refer here to Castoriadis (1999)[44], who states that the imaginary is defined by both its constitutive shift from the real and its fundamental role in the formation and conservation of social institutions.

The imaginary ecology of the nuclear industry structures communities by dictating a common planning horizon for all stakeholders in an industry marked by competition and recurrent conflicts (Hecht, 2014)[45]. Moreover, it has informed the design and realization of various technical devices, with the most important ones being: (a) the prototypes of FBRs—e.g., Superphénix, which was endowed with an unprecedented and symbolically significant power of 1,200 MW in part because it was thought to be the head of a series of future plants[46] —and (b) the expansion of the La Hague plant (the UP2 800 and UP3 facilities), which were intended to both produce larger quantities of reusable materials and ensure a maximum containment of residues through numerous auxiliary facilities. These devices are, therefore, technopolitical, in the sense given to this term by historian Hecht (2014)[47]: the facilities of the "cycle" were, by their very engineering, means to pursue an industrial policy strategy centered around this imaginary ecology. This imaginary, nonetheless, implies a sort of misunderstanding of the technicality that it mobilizes. As we have seen, the imaginary availability of energetic material and the reabsorption of residues by recovery come up against the technical constraints documented by safety engineers: the fragility and complexity of the technical systems that operate on the irradiated material, as well as the diffraction of the residues within an ever-expanding treatment network. This illusion is not a simple but an imaginary error, insofar as it reflects

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[44] Castoriadis (1999) is also one of the theoretical references cited by Jasanoff to develop her own concept of the imaginary. See also Lecourt (1974).

[45] Fast neutron reactors, in particular, offered a way to escape from the "*guerre des filières*" (a conflict centered on a rivalry between EDF and the CEA), which shook the industry between 1966 and 1969. This conflict also led to the abandonment of the so-called "French" sector of graphite-gas reactors developed by the CEA as part of the military program in favor of the "American" sector of pressurized water reactors under license from Westinghouse. For an analysis of this important and often forgotten episode, see Hecht (2014). Moreover, this imaginary provides the *raison d'être* of the CEA, and its mobilization allows the *commissariat* to maintain teams and funding.

[46] For an analysis of this point (and its symbolic dimension) inspired by the sociology of controversies, see Le Renard (2018).

[47] That is, the strategic practices of designing or using technology to set up, shape, and achieve political objectives (Hecht, 2014).

the interests of the industry (expressed in terms of profitability and efficiency) and translates the position of its promoters into representations. This is what I, inspired by Simondon, have called the “technocratic conception”: the technical operations disappear behind the promotion of a power over nature.

The construction of a complementarity between these two approaches meets a difficulty that must be explained to prevent it from being reduced to a simple superficial juxtaposition of two approaches. Jasanoff's analysis of the imaginary is essentially explanatory and descriptive: it entails giving an account of technical and scientific projects by bringing their sociopolitical motivations to light. The Simondonian analysis that I have proposed is normative, in that it intends to provide theoretical tools to identify and criticize the conceptual gaps between technical ensembles and their technocratic representation. In this sense, it conveys a form of critical epistemology of technology from which two presuppositions can be made explicit.

Firstly, it suggests that not all representations of technology have the same truth value. The gap between the conception of the promoters of the nuclear industry and the understanding of ensembles found in the literature on safety cannot be reduced to a simple difference between two incommensurable ontologies. The latter is truer than the former, especially in that it is nourished by investigations into the actual functioning of facilities. This comparison in terms of truth value allows us to reinvest, in a more flexible manner, the norm proposed by Simondon: the Simondonian technician is not the disinterested point of view from which a perfect description of technique would be stated but an ideal norm, susceptible to redefinition, towards which investigations must tend[48].

Secondly, it implies that technology cannot be dissolved in politics. We must distinguish between, on the one hand, the empirical observation of a co-construction or continuity (which STS studies document and analyze) and, on the other hand, the theoretical ambition of reducing technical objects to the status of sociopolitical agents like any other. This anti-reductionist perspective[49] gets through here by identifying the constraints specific to the technical reality, which I did here by mobilizing Simondon's ontology: technical ensembles are

[48] For this conception of truth as an effort towards an ideal standard, see Putnam's (1981) pragmatist epistemology.

[49] For a critique of sociological or anthropological reductionism, see also Putnam (1881).

irreducible to the technopolitical strategies in which they can be mobilized. In other words, there is an ontological difference between the technical operation (a causal system that links human invention and the natural environment) and the discursive operation that is played out in the formulation of imaginaries. The latter, in particular, encompasses a distorted representation of techniques: the one that sees them as the projection of a power over nature.

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