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Going beyond the Nuclear Controversy

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The controversy over nuclear power has been one of the fiercest scientific debates since the 1970s with a continuous evolution of the narratives used on the two sides.[1] The controversy can be attributed to the impossibility of generating a shared perception between social actors over the use of this technology. In fact, one can easily find contrasting—and even opposite—perceptions over nuclear power that simultaneously appears as "clean, secure, and cheap" to some, or "dirty, dangerous and not cost-effective" to others. Scientists are thus facing a clear dilemma when dealing with the "nuclear predicament". This problem lies in the unavoidable existence of different social actors expressing nonequivalent but legitimate perceptions of the same issue based on their values, beliefs and goals. This seems to demonstrate that there is no truth about nuclear power. There can be correctness, robustness, relevance, and usefulness of scientific information, but there cannot be absolute truth. After all, this is the counterintuitive narrative posed by the famous thought experiment of the Schrödinger's cat showing that information "per se" does not exist but rather is the result of a choice made by the observer in the way he/she interacts with the system.[2] Nuclear power is no exception. Any quantitative claim over the death impacts of nuclear power derives from a preanalytical choice over "what the system is" and "what it does". Therefore, claiming the existence of a "mainstream scientific consensus" over the death toll of nuclear power indicates that other legitimate perceptions have been disregarded at the time of formulating such conclusions.

This situation refers to the problem associated with the scientific elicitation of the effects on human health of low-level radiation from nuclear power. Indeed, this problem resides in the difficulty of measuring and quantifying this phenomenon over a long period of time. Consequently, there have been unavoidable contrasting knowledge claims expressed over this issue varying from "we don't know the effects" to "we know the effects and they don't matter" and "we know the effects and they are dangerous".

The frontier between knowledge and ignorance as regard nuclear power therefore is not clear, which in fact is the source of all troubles. For this reason it is crucial to be aware of the distinction between situations of *risk*—where it is possible to generate reliable scientific information—from situations of *uncertainty*—for which the unavoidable existence of contrasting knowledge claims does not allow us to reach a shared perception over the issue (Table 1).

The conventional formalization of "risk" considers only the immediate impacts to health and to infrastructures. This explains why, for example, coal mining is considered as more risky than nuclear power due to its higher death toll. Yet, extrapolating such a reductionist approach to longer time scales entails several epistemological problems. Among them is the fact that the long-term effects from nuclear power are inherently affected by indeterminacy and even genuine ignorance for which quantitative models lose validity. This is one of the main problems found in a paper recently published in this journal that attempts to evaluate the prevented mortality from nuclear power by mapping still debated historical records over the *short-term health impacts* of nuclear power to *long-term projections* of climate science.[3] Such assessment was made in spite of the fact that low-radiation is a typical situation where "risk" *cannot* be assessed using numbers and for which the engineering representations of systems lose validity. Unsurprisingly, the original paper rapidly generated a strong debate among experts, which further illustrates the topicality of the nuclear controversy.

The systemic controversy over nuclear power justifies the need to move from an engineering view to a societal view when discussing its quality as an alternative energy source. Such perception shift has crucial implications on the representation of nuclear power, in particular, over the definition of "what the system is" and "what it does". For instance, in the engineering view, the system nuclear power is often reduced to the size of the power plant. When considering the societal view, however, nuclear power is seen as a complex system not only described

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Table 1. Distinction between Situations of Risk and Uncertainty Associated with Nuclear Power (After Ref 1)

		uncertainty	
typology of "risk" *(availability of information)*	risk *(set of outcomes and probabilities are known)*	indeterminacy *(set of outcomes is known; probabilities are unknown)*	ignorance *(set of outcomes is unknown)*
examples	component failures (e.g., pumps, valves, reactor vessel, control rods, steam generator, containment, diesel generator); system failures (e.g., primary coolant loop, emergency core cooling system, high-pressure coolant injection system); high-level radiation	low-level radiation (reactor accidents and uranium mining activities); uranium ore grade; operating life of plant; R&D improvements; long-term capital costs	atmospheric science and geoscience (e.g., earthquakes, flood, tsunamis, tornadoes); human errors; terrorism; institutions; nuclear proliferation; long-term management of radioactive waste; social costs in case of accident
typology of systems	deterministic systems (mechanical behavior)	stochastic systems (indeterminacy, chaotic behavior)	complex systems (self-organization, emergence)

by its processes and facilities involved but also by its interaction with its societal context as an energy source.

The scientific information generated by the models developed under the engineering perception is certainly very useful to assess the reliability of nuclear energy systems. However, it is not sufficient to discuss the quality of those systems at the societal level. At this level, other analytical tools are required to address the complex nature of nuclear power characterized by multiple scales at which this technology can be perceived. This can be achieved by performing a "multi-scale integrated assessment" of nuclear power[1] which implies mixing quantitative analysis with qualitative analysis so as to change the focus of the discussion from "truth" to "quality".[4] This forces us to revisit the role of scientists when using science for governance. Scientists should accept to return to be considered as another category of social actors rather than pretending to be referees above partisan interests. Doing so requires however new procedures and new rules able to deal with the unavoidable existence of multiple relevant scales to be considered in the quantitative analysis of complex systems, such as nuclear power when observed from the societal view.

Adopting a societal view can be very beneficial to the scientific discussion over the quality of nuclear power as it makes it possible to revisit the conventional narratives set forth by the engineering perspective. For instance, from a societal view, nuclear power can no longer be considered as a "low-carbon" energy source due to the significant dependence on fossil-fuels required by the processes and facilities making up the whole nuclear power system.[5]

A sound discussion over the desirability of technology can start with touching upon engineering knowledge but cannot be done without engaging in an in-depth characterization of the system from a societal perspective for which another type of knowledge applies. This is of paramount importance if one is serious about facing the controversy over nuclear power.

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Notes

The authors declare no competing financial interest.

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