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Like a bridge over troubled water – Opening pathways for integrating social sciences and humanities into nuclear research

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ABSTRACT

Research on nuclear technologies has been largely driven by a detachment of the 'technical content' from the 'social context'. However, social studies of science and technology - also for the nuclear domain – emphasize that 'the social' and 'the technical' dimensions of technology development are inter-related and co-produced. In an effort to create links between nuclear research and innovation and society in mutually beneficial ways, the Belgian Nuclear Research Centre started fifteen years ago a 'Programme of Integration of Social Aspects into nuclear research' (PISA). In line with broader science-policy agendas (responsible research and innovation and technology assessment), this paper argues that the importance of such programmes is threefold. First, their multi-disciplinary basis and participatory character contribute to a better understanding of the interactions between science, technology and society, in general, and the complexity of nuclear technology assessment in particular. Second, their functioning as (self -)critical policy supportive research with outreach to society is an essential prerequisite for policies aiming at generating societal trust in the context of controversial issues related to nuclear technologies and exposure to ionising radiation. Third, such programmes create an enriching dynamic in the organisation itself, stimulating collective learning and transdisciplinarity. The paper illustrates with concrete examples these claims and concludes by discussing some key challenges that researchers face while engaging in work of this kind.

1. Introduction

Research and policy-making in the field of nuclear technology and radiation protection has been typically grounded on a split between 'technical content' and 'social context', with a strong division of labour between natural and social scientists and a division of competences between 'experts' and 'the public'. However, following controversies related to nuclear accidents, the use of nuclear technology for military purposes, and the management of radioactive waste, the need for multi-disciplinary research and broader societal involvement in nuclear decision-making is increasingly recommended at national and supra-national levels for all aspects of the nuclear fuel cycle (Schröder and Bergmans, 2012; IAEA, 2002; Hedemann-Jensen, 2004). Examples include uranium mining (IAEA, 2009, p.3), the siting of new nuclear power plants (e.g. NRC, 2004), emergency situations (ICRP, 2009, p.12, p.23), rehabilitation of contaminated territories (OECD, 2006; Till, 2008), and radioactive waste management (Bergmans et al., 2008, p.25). This is reflected more and more also in European research programmes. A first attempt to integrate social sciences and humanities in European nuclear research has addressed issues of public participation and democratic decision-making in the siting of radioactive waste disposals (e.g. the E.C funded projects COWAM, ARGONA, CARL). Recent projects (e.g. OPERRA, PREPARE, EAGLE, CONCERT) seek to extend this integration to larger domains, such as radiation protection research, or specific areas, such as emergency management and rehabilitation of contaminated areas.

The call to integrate the links between research, innovation and society is not unique to the nuclear field; it is rooted in decades-old visions for collaboration between scientists, technologists and social scientists (Owen et al., 2012). It also aligns with recent proposals for more open and responsive modes of research and science policy-making, as illustrated by contemporary EU-wide policy discourses on "Science with and for society" and "responsible

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research and innovation". These policy discourses in turn build on interdisciplinary research fields such as science and technology studies (STS) and technology assessment.

The Belgian Nuclear Research Centre SCK•CEN initiated in 1999 its 'Programme for Integration of Social Aspects into nuclear research' (PISA). The aim was to unfold the societal, political, cultural and ethical aspects related to the development and use of nuclear technologies and guide policy in these areas. Put differently, PISA research aims at bridging nuclear science and society, by investigating how the two interact and how this interaction could be improved. The emergence of the programme inside a technical research institute was the result of an internal reflection acknowledging that insights from social sciences and humanities were required to better understand normative concepts that came to the fore at the time, such as precaution, sustainable development or safety culture (Eggermont, 2001). Given the status of SCK•CEN as a foundation of public utility, the establishment of the PISA programme was seen not only as an opportunity to explore alternatives to the so–called technocratic approach to science and technology development, but also as a responsibility towards society. From the onset of PISA, interaction has been sought with various stakeholders: researchers from nuclear and non-nuclear fields, policy-makers, representatives of the industry and members of the organised civil society or the lay public, with the aim of developing multidisciplinary and inclusive research activities.

This paper looks back at the fifteen years of PISA activity in order to illustrate and discuss this aim and ways to achieve it. It first situates PISA within the field of Science and Technology Studies (Section 2). It then discusses (Sections 3–6) the four current research strands: i) ethics of nuclear technology assessment; ii) radioactive waste management; iii) nuclear safety governance; and iv) perception and communication of nuclear risks. The first three strands focus on particular aspects of the life cycle of nuclear technologies, while the fourth is a transversal theme. Analytical insights derived within these research strands are highlighted, alongside practical implications, with special attention to their added value for nuclear and radiation protection research in general, and for the Belgian Nuclear Research Centre and the relevant stakeholders in particular. The final section highlights the challenges of reflective research programmes such as PISA, as well as their relevance for guiding practice and policy on complex and controversial issues such as the use of nuclear technology. It does so by identifying and discussing key challenges inherent to research located at the science-policy interface: independence, credibility, continuity and impact.

2. The PISA programme: an STS approach to nuclear technology

The establishment of PISA within SCK•CEN resonated with wider calls within the field of research and innovation studies. The need for multi-disciplinary and multi-stakeholder research frameworks – where the intertwined character of the social and the technical is the object of analytic engagement – is increasingly emphasized in social studies of domains pertaining to science and technology (Hackett et al., 2008), including that of nuclear technology (see e.g. Wynne, 1989, 1992; Jasanoff and Kim, 2009; Hecht, 2009; Pfotenhauer et al., 2012). The idea is that science and technology are "open to individual creativity, collective ingenuity, economic priorities, cultural values, institutional interests, stakeholder negotiation, and the exercise of power" (Stirling, 2008, p.263), and it is thus important to reflect on how this shapes the organisation of research and the formulation of policies.

Science and Technology Studies analyse science and technologies in their social contexts, as social phenomena in themselves. Whether it is only the 'context' that is social, while the 'content' remains to a certain degree independent, continues to be subject of discussion in this field (see e.g. Bijker and Law, 1992, p.201). It is, however, generally accepted in academic research and policy-making that there is at least an interaction between politics, values, culture, economics and regulations that influence science and technology, and vice versa (Jasanoff et al., 1995). Against this background, *technology* has at least three layers of meanings (Bijker, 1995): it encompass not only physical artefacts (such as a waste disposal facility, a radiological assessment tool or an incident reporting database), but also human activities (e.g. the process of analysing monitoring data or the reporting of incidents in a nuclear installation), and knowledge (e.g. models, lessons learned from past incidents).

Two notions are central, throughout STS in general and with respect to PISA work more specifically. The first is the notion of *co-production*, an interpretative framework for studying "the complex linkages among the cognitive, the material, the normative and the social" (Jasanoff, 2004, p.274). Co-production captures the understanding that science and technology are "neither a simple reflection of truth about nature, nor an epiphenomenon of social and political interests" (Jasanoff, 2004, p.3): both are mutually shaping. Along this line, STS scholars try to explicate the links and interactions between science, technology and society. This "capacity to understand how it is that people and technologies work together, shape one another, hold one another in place" is indispensable, because society cannot function without science and technology any more than science and technology can exist without appropriate social support (Jasanoff, 2004). For instance, (a part of) the Belgian society shaped the country's nuclear energy provisions, as much as the nuclear energy technology shaped Belgian society itself (Laes et al., 2007).

A second central notion in STS is that of *interpretive flexibility* (Pinch and Bijker, 1984; Bijker and Law, 1992); this implies that neither nature, nor society alone can speak clearly and unambiguously enough to prevent contestation. A clear illustration from within the nuclear field is the discussion about the health effects of low doses of radiation and the perception of these effects depending on the specific context of occurrence (e.g. Turcanu and Perko, 2014). Interpretive flexibility opens not only the possibility, but first of all the *necessity* for negotiation (Knorr Cetina, 1995, p.152). Controversies are thereby treated not as a threat, but as inevitable and potentially generative (Sismondo, 2008, p.14). One of the key interests in STS is to study what is at stake in controversies, how they get settled, and which "closure mechanisms" can be identified (Bijker, 1995, p.252). As such, STS also offers "a way of interpreting and accounting for complex phenomena so as to avoid strategic deletions and omissions" (Jasanoff, 2004, p.3).

The motivations for using STS as inspiration for PISA research are its capacity to provide a better insight in the epistemic and normative complexity of the nuclear issue (descriptive and explanatory purpose) and its potential to instruct normative policy guidance (prescriptive and moral purpose) (Jasanoff, 2004, p.17). These two aims are sometimes referred to as the High and the Low Church of STS. The former is more an 'academic' or 'fundamental' research endeavour of developing conceptual tools for exploring the development and stabilization of knowledge, artefacts and social orders. The latter is more of a 'policy oriented' or 'applied' research effort, concerned with making science and technology more accountable to public interests (Sismondo, 2008, p.18). For PISA, as located within a research centre of public utility, both aims are relevant, as illustrated by the research examples presented in the next sections.

3. Ethics of nuclear technology assessment

3.1. An ethics of reflexivity

PISA research on the ethics of nuclear technology assessment is grounded in two theoretical lines of reasoning. The first line describes nuclear energy technology as a typical artefact of modernity in the sense that, similar to the case of fossil fuels and climate change, society became 'confronted' with the adverse effects of its application. The second theoretical line emphasises the epistemic complexity of knowing and evaluating the issue. Due to the character of nuclear risk, the evaluation of its potential adverse effects and of the possibility of their avoidance or control is complicated not only by the knowledge-related uncertainty (due to incomplete or speculative knowledge), but also by moral pluralism. The latter means that even if all actors agreed on the knowledge base for the evaluation of nuclear risk, their opinions on its acceptability could, and probably would, still be different.

Drawing on a number of theories of modernity (e.g. Beck et al., 1994), we argue that the traditional 'governing modes' of society, being representative democracy via party politics and bound within the nation state, the liberal market, 'objective' science and education organised within disciplinary boundaries, are essentially not capable of grasping the complexity of evaluating the possible use of nuclear technology to the full extent. As a consequence, they are, each in their own way, unable to contribute to generating societal trust with either decision (acceptance or rejection) on the technology. The stimulation of critical thinking in education, the inclusion of civil society and transdisciplinarity in research and the ideal of deliberative democracy for decision making have been rightly proposed as advanced approaches to 'better' cope with the complexity of issues such as the use of nuclear energy (Funtowicz and Ravetz, 1993; Stirling, 2008; Voss et al., 2006; Nussbaum, 2012; Asveld and Roeser, 2008). The need for these approaches however cannot be motivated on the basis of an 'advanced' rational understanding of complexity, but should be grounded in a normative 'ethics of reflexivity'. This ethics should *inform* and *enable* methods of democratic decision making, policy supportive research and education that would, 'by design', generate societal trust. Specific for the nuclear case is that a deliberate approach to the issue is today troubled by a 'comfort of polarisation' that not only affects the quality of public discourse, but is also deeply rooted in the organisational structures of politics, science and informed civil society (Meskens, 2013). Overcoming this comfort of polarisation is not just a matter of political will, but essentially requires the stimulation of new thinking modes in politics, research and education.

In broad categories, the ethical perspective outlined above is applied in PISA research to: (1) the issue of justification of nuclear technologies in energy governance, (2) the role and responsibility of science to provide policy advice and (3) the potential and the limitations of the radiological protection system (as a regulatory framework) to provide 'ethical guidance' to research and policy. The basic idea that underpins the research on justification is that 'fair and effective risk governance' should be inspired by the insight that people will accept a risk they cannot completely know and that they cannot fully control simply when they trust that its justification is marked by fairness. In turn, this idea of fairness instructs the necessity to involve the 'potentially affected' in knowledge generation and decision making on nuclear, taking into account that decision-making might lead to acceptance, as well as to rejection of the risk-inherent technology.

This strand of PISA research is also reflected in the growing number of projects on ethics related to the radiological protection system (see, among others, Eggermont and Feltz, 2008). Inspired by our 'ethics of reflexivity' approach, we claim that an ethical stance with respect to the relevance and use of the radiological protection system implies the recognition of the limits of the system when it comes to providing a rationale for societal justification of nuclear risk. In other words, the radiological protection system cannot and should not be 'stretched' to provide the full rationale for societal justification, but it can and should generate critical considerations on how our formal methods of knowledge generation and decision making should foster involvement of potentially affected persons and promote fairness in justifying radiation risks.

3.2. Reaching out to researchers

A research programme concerned with an 'ethics of reflexivity' for nuclear technology assessment logically includes a focus on the working of science as policy advice in a democratic decision-making context. A reflection group process on the issue of 'ethics and expert culture' was launched in 2001 (Eggermont, 2001) to stimulate an internal dialogue on research ethics in the context of the renewal of the own SCK•CEN Ethical Charter. Worthwhile to note is that this research has resulted in a course programme on the topics of nuclear risk, ethics, science and democracy that is now lectured on invitation in various university education programmes throughout Europe and that is also introduced in Belgian education and training programmes related to radiological protection and nuclear engineering. The lecturing practice is supported by a policy track concerned with introducing ethics in 'traditional' radiological protection and (nuclear) engineering programmes. This policy track, under the title of 'Caring for Critical-Intellectual Capacities' is organised in cooperation with the SCK•CEN Academy for Nuclear Science and Technology.

4. Radioactive waste management: addressing the Faustian bargain?

4.1. Explicating socio-technical interaction in theory

Radioactive waste, especially high-level, long-lived radioactive waste, has often been called the Achilles' heel of nuclear power (Brooks, 1976; Blowers et al., 1991). The well-known American nuclear physicist Alvin Weinberg referred to it as the Faustian bargain of nuclear energy: "the price that we demand of society for this magical energy source is both a vigilance and a longevity of our social institutions that we are quite unaccustomed to" (Weinberg, 1972, p.33). Nevertheless, the large majority of radioactive waste management (RWM) research has been and continues to be dedicated to techno-scientific issues (Solomon et al., 2010). Furthermore, despite the call for stakeholder involvement in all stages of the planning and development of the disposal process (ICRP, 2013), technical strategies are mostly constructed independently and social or ethical dimensions are addressed in a later phase (e.g. at the stage of siting, in light of public controversy). Alternatively, they are addressed in parallel, by different teams and with very little interaction (Bergmans and Schröder, 2012; Martell et al., 2014; Martell and Van Berendoncks, 2014). Current activities by RWM actors, notably in the framework of implementing geological disposal of radioactive waste, can indeed be described as an ongoing struggle to integrate and/or disintegrate social and technical issues, and to find a balance between 'opening up' and 'closing down' technological options and decision-making procedures (de la Bruhèze, 1992; Stirling, 2008; Barthe et al., 2014).

It is this struggle that lies at the core of current PISA research on radioactive waste management. One of the theoretical frameworks underlying this study is Actor Network Theory (ANT). This describes technologies as networks: hybrid collectives of humans (e.g.

waste management agencies, regulators, and local communities), non-humans (e.g. clay, waste fractions, and copper canisters) and everything in between that associates them (knowledge, instruments, practices). All elements within such a network have to work together and stay in alignment, and the more ‘allies’ enrolled in the network, the stronger it becomes.

An actor network analysis aims at investigating how networks come into being, which associations exist between actors, how they are enrolled into a network, and how networks achieve stability (Cresswell et al., 2010). It thus highlights that whether a technology works or not depends as much on technical, as on social variables, or, better, on the strength of the socio-technical network they form together. We argue that this is also the case for the technology of geological disposal (GD), even though it is presented as a strategy that ultimately functions without human involvement and in isolation from society (Schröder, 2015a). Think for instance of the topics of reversibility and retrievability or long term memory preservation. They require both 'technical' (e.g. removable backfill/markers) and 'social' (e.g. decision making procedures/people that understand marker messages) research and structures: one does not make sense without the other, both are needed and compatibility is required. Even though the technology of GD is typically referred to within a ‘negative’ functional framework of reducing risks by means of passive safety and by not passing undue burdens to future generations, we thus equally want to explore the purposive, functional, active and generative role it holds in shaping the future (Berkhout, 2006), i.e. the impact is *does* have on future generations. The more you acknowledge that every intervention in the natural and the material realm is also an intervention in the social order, the more careful you become (Latour, 1993, p.42). In this regard we also draw on frameworks that describe innovation not only as technical, but also as social experimentation, and that look for the most responsible ways to do so (e.g. van de Poel, 2011).

4.2. Encouraging socio-technical interaction in practice

To study the construction of socio-technical networks an ‘ethnographic approach’ is advocated, based on extensive fieldwork and participant observation “on the production site” of the technology (Buzelin, 2005, p.198). In this regard the location of the PISA programme *within* a nuclear research centre is advantageous both to study the waste research as it is being conducted within SCK•CEN, and as a vantage point to participate in international radioactive waste management networks (such as the those of the OECD-NEA and the IAEA).

Within SCK•CEN, research practices are facilitated and stimulated that do justice to the socio-technical character of RWM, by organising exchanges between the social and technical groups working on RWM inside SCK•CEN (e.g. Schröder, 2014). These exchanges bring together people working on the same topic or within the same policy framework, but from different angles. Such exchanges are meant to get to know each other's work better, to improve internal communication, to encourage bottom up critical reflection and to integrate technical and social research in common projects. Valuable lessons are learned with regard to differences and similarities in research approaches, views on the meaning of expertise, or on dealing with uncertainties. One session revealed for instance that people working respectively on geological disposal and advanced nuclear technologies may have different conceptions about responsibilities towards future generations or the technical translation of such values within the high-level waste debate (Schröder, 2015b). Another session brought forward that waste characterization includes not only technical aspects (e.g. related to monitoring equipment), but also political (e.g. who controls the characterization process) or economic considerations (e.g. related to the influence of waste categorization on waste prices). This among others explains, and concurrently is explained by national differences – even within Europe – with regard to characterization standards, practices and policies. Such exchange sessions encourage researchers to consider “the drivers, modalities and potential outcomes of their work whilst it is being conducted, from experimentation to dissemination” (Fisher and Mahajan, 2006) and thus stimulate responsible innovation.

5. Governance of nuclear safety

5.1. Beyond safety culture: towards a vulnerability-based approach to technological culture

After the accident of Chernobyl, safety culture - as an object of knowledge - has increasingly become the focus of attention in many scientific disciplines in order to explain safety issues and ultimately to prevent accidents (Henriqson et al., 2014). In this respect, Henriqson et al. (2014) identify two main approaches to safety culture, both of which having been approached in PISA research. First, an interpretivist approach has been used to determine what an organization does in relation to safety values, beliefs and behaviours. Within this approach, qualitative methods are employed to characterize the continually redefined and negotiated safety culture of the organization. This “thick description” (Geertz, 1973) of safety culture(s) to be observed at SCK•CEN (Fucks, 2004) has been complemented with a second, functionalist approach to safety culture. The latter departs somehow from a classical STS constructivist approach as it aims at determining what an organization has in relation to safety values, beliefs and behaviours. This framework seeks to quantify and measure safety culture factors, for instance through questionnaires.

5.1.1. From safety culture ……To technological culture(s)

Recently, an STS vulnerability-based framework (Hommels et al., 2014) is being investigated within PISA (Rossignol et al., 2014a, 2014b) in order to bring new insights into safety governance. Three major claims – which can be translated into research heuristics - constitute the core of this new approach. First, “technological cultures” become the central concept to be characterized, as this shapes the vulnerability of a socio-technical system (Bijker, 2006). This invites to trace vulnerability's relation to the (intended and unintended) effects of technologies or lack thereof. Second, this approach is context-based, vulnerability being considered as an emergent property that results from an evolving social construction shaped by technological cultures. It suggests that general/top-down rules to manage vulnerability may be subject to local negotiations and reconstructions in order to fit specific contexts. Finally, this perspective aims to engage with a pragmatic way of thought based on gradualism, rather than dualism, according to which situations are never only “good” or “bad, “black” or “white” (Keulartz et al., 2004).

This new approach serves as a vulnerability-based theoretical framework for on-going research focusing on Incident Reporting Systems (IRS) used at SCK•CEN. The aim is here to characterize the technological culture, i.e. a shared set of principles, values and practices specific to a group of people when it comes to a specific technology, in this case the IRS. The research draws on semi-structured interviews realised with employees of the Centre. The first analysis (Rossignol and Claisse, 2014) shows that incident reporting practices are not only more varied than the institutionalised way of reporting by using the system, but also embedded in different expressions of solidarity. This denotes the interpretative flexibility (Pinch and Bijker, 1984) of what means the IRS and what means “reporting an incident”, that seems to be overlooked by the organization itself. By detailing the various reporting practices identified in relation with their expression in terms of solidarity, this research contributes to informing a reflection in terms of vulnerability that is grounded on both the interviewees' evaluation, as well as the organisation's own terms. A qualitative study in situ, allowed displaying emergent properties of the on-going reporting processes, characterised by a specific culture. The context-based analysis pointed out that these properties can be evaluated both positively and negatively depending on the perspective adopted. For instance, not reporting formally an incident is not – surprisingly - always a bad thing, since it doesn't automatically threaten safety and can be also the counterpart of an informal reporting that targets a local and more meaningful learning process. Further analyses focus on the characterization of the modes of learning enacted by the different reporting practices is under scrutiny.

This promising yet tentative path of study will be followed in the future, hopefully also in other case studies, in order to test its heuristic capacity and to open up the research on safety culture to other modes of thinking and possibilities of action.

5.2. Planning and response for nuclear emergencies: confronting paper plans with reality

Emergency planning is deemed to be the cornerstone of an effective response to nuclear or radiological events leading the contamination of the environment and potential impacts on people and goods. Technical aspects such as the risk analysis of potential threats and the protective actions that can be taken to mitigate the potential consequences for people and the environment are at the very heart of emergency plans. Clarke and Perrow (1996) argued however that emergency plans for complex installations are "fantasy documents" that may miss reality checks. First, because the "historical record is absent or unrepresentative" (Clarke and Perrow, 1996, p.1053), and second, because such plans cannot cover all possible scenarios and "each accident may be different enough to be off the plan's map" (Clarke and Perrow, 1996, p. 1053). For this reason, Lagadec (2009) points out the importance of an on-going planning process, anchored more in reality than in principles and doctrine.

In light of the STS view on the different layers pertaining to a technology, PISA research investigates cultural, behavioural and risk perception factors influencing the effectiveness of emergency response, as well as ways to enhance participation in drafting and assessing emergency plans through an on-going creative process. The findings are particularly relevant for SCK•CEN, given its role in the Belgian national emergency plan, its members acting as radiological advisors, participants in and organisers of regular emergency exercises and trainings.

5.2.1. Acceptance of residual radioactivity is influenced by trust in legal norms

Research grounded on empirical data from a large scale public opinion survey carried out at regular intervals in the Belgian population brings useful insights into their acceptance and compliance with emergency management actions in case of a nuclear emergency. It showed for instance that the acceptance of risks associated with residual radioactivity in food in a post-accident situation depends not only on the specifics of the individual countermeasures applied, but also on the trust in the underlying legal system (Turcanu et al., 2007). This highlights the need for harmonisation at the European level – where Member States hold the decision power concerning the norms applied for food consumption within the country- or even worldwide. A model based on the theory of planned behaviour (Ajzen, 1991) further showed that apart from trust in legal norms, intended consumer's behaviour towards food products with residual radioactivity is significantly influenced by people's attitudes (e.g. health concerns, justification) and subjective norms (perceived support from their close environment related to the use of such products) (Turcanu and Perko, 2014).

Finally, the mere notions of radioactivity and contamination appear to have a negative impact on the perception of residual radioactivity after an accident, leading to a strong reluctance towards consuming food products from the affected areas even if these products satisfy the legal norms (Turcanu et al., 2007; Turcanu and Perko, 2014).

5.2.2. Stakeholder processes: a reality check for emergency plans

Stakeholder processes organised in the framework of several projects with involvement of PISA researchers enhanced the technical experts' awareness of aspects related to the feasibility and social acceptance of potential countermeasures in emergency management (Vandecasteele et al., 2005). At the same time, such processes allow the technical experts to be confronted with and better understand the reality and values underlying stakeholders' viewpoints and thus to contribute to continuously improving emergency planning and related decision-making. A stakeholder panel focusing on the management of consumer goods (Turcanu et al., 2015) highlighted for instance outstanding needs in emergency preparedness, e.g. a thorough analysis of stakeholders potentially affected and the type of information they need in order to ensure fast and efficient communication, and a better management and sharing of information about protective actions for the food chain. In addition, more focus has to be laid on socio-economic aspects, e.g. compensation schemes and distribution of costs, and the long term phase of post-accident management, e.g. clear definition of responsibilities.

When it comes to the involvement of lay public in decisions related to emergency preparedness, this poses several challenges. Empirical research highlighted an important decrease between 2002 and 2009 in Belgium in the percentage of people willing to participate in decision processes concerning installations with risks (Perko et al., 2010). Higher willingness to participate was expressed by people with higher interest in science and technology, lower confidence in authorities and, surprisingly, lower perception of industrial risks (Turcanu and Perko, 2011).

6. Perception and communication of radiation risks

As shown again in the case of the 2011 accident in Japan (NAIIC, 2012) and demonstrated on a daily basis in relation to siting of radioactive waste disposal (Trettin and Musham, 2000), construction or decommissioning of nuclear installations (Song et al., 2013), environmental remediation processes (IAEA, 2011) or nuclear energy policy (He et al., 2013), communication in the nuclear field has to be improved. An important question is how to improve communication about nuclear issues among nuclear industry, scientists, authorities, NGO's, population and other members of informed civil society. We argue that an integrated approach is needed, bridging several fields, among which risk communication, risk perception, behavioural sciences, nuclear research and radiation protection.

6.1. Risk communication strategies should not focus solely on enhancing specific knowledge

The amount of knowledge people hold about nuclear technology affects their capacity to gain new information about it, but has only a limited effect on their agreement with the messages communicated. PISA studies on communication in nuclear emergencies (Perko et al., 2014a; Perko et al., 2013) confirmed the findings from political communication (Price and Zaller, 1993; Zaller, 2006) that: i) specific knowledge is the dominant predictor for receiving, comprehending and recalling communicated messages; and ii) knowledge does not have a significant influence on the agreement with these messages. Instead, the perceived disaster potential of a nuclear accident is the most influential predictor for the agreement with communicated messages. However, specific knowledge acts as a facilitating variable for the agreement with protective actions; a joint effect of specific knowledge and some risk perception characteristics, for instance dread, could be observed (Perko et al., 2014a).

Moreover, as proven in the context of public communication campaigns, for instance on nuclear waste disposal, higher prior knowledge does not affect people's perception of the specific risk communicated (Perko et al., 2012b). Therefore, although information campaigns are usually centred on increasing knowledge, effective risk communication about nuclear technologies has to take into consideration also risk perception.

6.2. Media do more than simply provide information about nuclear technology

Kasperson et al. (1988) point out that media can change the original message by intensifying, weakening and/or filtering the information. Media are thus not neutral intermediaries of information: they modify the information in the process, and this might influence the recipients of their messages. A PISA study on the perception of health effects of the Fukushima nuclear accident among the Belgian population (Vyncke, 2014) showed that the use of certain media channels is a significant predictor for the perceived risk from a nuclear accident. However, this influence is low compared to that of other variables, such as the general attitude towards nuclear energy.

Research results also showed that when reporting about the Fukushima accident, media were more interested in reporting about emergency response and radiological risk related to the immediate consequences than about general safety (e.g. safety standards), emergency planning or recovery processes (Perko et al., 2014b; Perko, 2011). They preferred to present visuals (illustrations, graphics), rather than detailed technical or scientific information about nuclear technologies (Perko et al., 2014b). At the same time, risk comparisons (e.g. with workers' exposure, background radiation or legal limits) were preferred by the media to the mere reporting of scientific quantities (Perko et al., 2014c). Finally, stories linked to our collective memory, for instance the nuclear accident in Chernobyl, were often present in newspaper articles about the Fukushima accident (Perko and Turcanu, 2013) or even about minor nuclear events (Perko et al., 2012a).

6.3. Different radiological risks and different population groups, rather than a general perception of “radiological risk”

A number of PISA studies (Turcanu et al., 2011; Turcanu and Perko, 2014) confirmed the existence of at least two latent constructs related to the perception of radiological risks. The first includes risks that can be linked to the nuclear industry: an accident in a nuclear installation, radioactive waste, residues of radioactivity in food and a terrorist attack with a radioactive source. These risks are generally perceived as high risks. The second clusters other radiological risks: medical X-rays, radiation from mobile phones and natural radiation. These are perceived as low risks. This shows that there is no generic concept of “radiological risk”.

Moreover, numerous studies showed that experts and the public frequently disagree when it comes to risk assessment (Hamalainen, 1991; Sjöberg and Drottz-Sjöberg, 1991; Purvis-Roberts et al., 2007; Skarlatidou, Cheng et al., 2012). Results of empirical research conducted within PISA showed that people working in a nuclear research environment perceive medical X-rays significantly higher than the general population. Opposite to this, they perceive risks from nuclear waste, natural radiation or an accident in a nuclear installation lower than the lay public (Perko, 2014). However, there are differences also among those with knowledge about ionising radiation. For instance, perception of risks from nuclear waste or accidents was shown to be influenced by the number of years of experience in the nuclear field, the frequency of professional exposure to ionising radiation, the feeling of being protected against risks from nuclear installations (in general) and the level of perceived control by authorities on the safety of nuclear installations (idem).

6.4. Stakeholder involvement increases mutual understanding in the communication between experts and the public

As argued in section 3, stakeholder involvement in decision making related to nuclear technology applications can be considered as a principle of fairness of the decision making process. The involvement of potentially affected citizens and interest groups with different visions on nuclear enables a formal confrontation of arguments. In that sense, a well-moderated inclusive decision making process can contribute to generating transparency with respect to the specific interests and the rationales used to defend them. As this is an essential factor of trust building, stakeholder involvement is considered to increase the efficiency of the decision-making process, whatever the outcome of that process would be.

This latter claim has also been confirmed empirically in a PISA study that investigated how people processed information provided in a public information campaign related to nuclear emergencies (Perko, 2012). The aim was to determine whether the lay public processed this information in a heuristic way (instinctive or emotion driven) or a systematic way (based on rationality), making more effort to process and check the information and to take a decision. Results showed that a higher acceptance of communicated information occurred among people who processed the information in a systematic way, who had more trust in experts and higher confidence in authorities. Decisions taken as the result of a stakeholder involvement process are therefore more stable, since this provides an opportunity for systematic information processing, which, in turn makes that information stays longer in our memory and leads to more permanent decisions (Petty and Cacioppo, 1986).

7. Challenges and added value

In the previous sections we introduced theoretical concepts and illustrated with several examples the results from a multidisciplinary research programme with a nuclear research centre. As mentioned at the outset, PISA research has two purposes: an academic, descriptive one and a normative, policy supporting one. The table below summarises the examples discussed and their point of focus: either development or functioning of nuclear technologies Table 1.

Based on the previous considerations, we argue that research programmes such as PISA are valuable and needed. However, this kind of research will always need to take into account challenges *inherent* to that research approach. Some of these are briefly addressed below.

7.1. Independence and credibility

A key challenge for research programmes such as PISA is their independence and credibility. While performing research from out

Table 1
Examples of PISA research: from analysis to research in action.

	Analysis (development of concepts and tools)	**Research in action** (policy and decision support)
Development of technologies	Waste management: research on geological disposal	Internal exchanges related to new nuclear technologies
	Justification of the use of applications of ionising radiation	Ethical charter of SCK•CEN
Functioning of technologies	Safety governance: vulnerability analysis framework	Analysis of incident response systems
	Emergency planning: behavioural or risk communication models	Stakeholder involvement processes
	Risk perception models	Communication guidelines

of a 'neutral' university environment may not necessarily guarantee independence and credibility as such, one can reasonably expect scepticism with respect to the independence and credibility of critical-reflective research on nuclear technology done from out of (and sponsored by) a nuclear research centre. The previous considerations on PISA research activities show that this research is done with a continuous awareness of its being located within a nuclear research centre, but that is obviously not enough. More important perhaps is that PISA researchers increasingly receive invitations to take up an advisory role on nuclear-related policies at the science-policy interface. Key examples include a study on the history of the societal debate on nuclear energy (Laes et al., 2007) for the Flemish Institute for Science and Technology Assessment, a contribution on 'Ethics of Nuclear Energy' in the Science Policy Commission of the Belgian Parliament, the participation to the European Interdisciplinary Study on 'Benefits and Limitations of Nuclear Fission for a Low Carbon Economy' (European Economic and Social Committee, 2012) and the chairing of the advisory expert committee on options for the national nuclear fuel cycle, undertaken by the Belgian Federal Public Service Economy, SMEs, Self-Employed and Energy. While these examples obviously do not prove PISA's independence, they may be understood as a sign that its input is valued and increasingly called for at the policy level.

7.2. Continuity

A science and technology studies approach applied to the issue of nuclear technology obviously also needs to embed scientific and technical knowledge related to the technology as such into its contextual considerations. The establishment of a research group such as PISA within a technical research centre (in this case with a focus on nuclear technology) not only ensures 'direct access' to state-of-the-art scientific and technical knowledge but, vice versa, but can also directly stimulate the 'enrichment' of this knowledge with these contextual reflections (see also Kleinman and Vallas, 2001). In universities, research on social, political or ethical aspects related to the applications of ionising radiation is generally organised in studies of limited duration, most of them in the form of doctoral dissertations. For institutions concerned with nuclear policies in the widest sense, the continuous access to the knowledge developed by groups such as PISA provides them with an opportunity to inspire their own working (e.g. on the development of policy guidelines) with contextual reflections derived from a social sciences and humanities perspective. Examples include the IAEA guidelines on communication and stakeholder involvement in emergency situations or remediation processes (IAEA, 2014; IAEA, 2012).

In terms of scientific relevance, our experience showed that collaboration with the academic world (for instance through collaboration on PhD and Master programmes) benefits the generation of new ideas and helps enriching the methodological resources and keeping up to date with the state-of-the-art.

However, ensuring the relevance of PISA research in the nuclear policy arena requires not only a permanent monitoring of social and political evolutions, but also, and primarily, a continuous effort to motivate the integration of a critical social sciences and humanities perspective in nuclear research projects. While latest developments in European research policy lay greater emphasis on multidisciplinary research and participatory decision making processes, there is still a large effort needed to attain these objectives in the nuclear field.

7.3. Impact

One of the first difficulties recognized from the onset of PISA was the lack of a 'common language', not only between technical experts and the lay public or other stakeholders, but also between experts themselves, when they belong to different domains. Although multi-disciplinary teams are now promoted in several research contexts, there is still little experience with bringing together researchers from social sciences and humanities and technical disciplines. Therefore, the development and use of a common language that would enable to speak in a deliberate and reflexive way about the issue of risk-inherent technology applications may have a valuable impact on the quality of research, both in its advisory role towards policy as in the way it can contribute to a more effective communication with the general public. Obviously one must recognise that the impact of our research can never be 'measured' in an objective way. In accordance with our reflection on independence and credibility above, we suggest that the growing response on PISA work from out of civil society and the political context may at least be seen as an indirect sign of its impact in one or other way.

Finally, one of the most important and, we believe, most effective forms of impact of our research is the introduction of specific courses in existing traditional academic and professional education programmes. We claim that courses that put the use of nuclear technology in a broader societal perspective contribute to stimulating 'reflexivity' as a critical-intellectual capacity of nuclear students, trainees and PhD researchers. Whether in the context of energy production or medical applications, the aim is to sharpen and stimulate their critical sense with regard to the scientific, psychological, social, political and ethical aspects of evaluating and applying nuclear technology applications, and with regard to their own rationalities (and those of others) in this respect. We work together with the SCK•CEN Academy for Nuclear Science and Technology to reflect on form and content of these courses, and the role of SCK•CEN as a main actor in education in training in the nuclear field within Belgium and in Europe, and its participation in international education and training programmes, facilitated the introduction of such topics in academic and training curricula.

8. Conclusion

With a number of examples throughout the paper, we illustrate how the social sciences and humanities can be integrated into nuclear research and how this integration can make research more reflective and more responsive towards society. We claim that this character of reflexivity can be called the central added value of such an exercise in three respects. First, PISA experience shows that such research creates an interesting and enriching dynamic in the organisation itself. Second, the scientific basis and the multidisciplinary and participatory character of the research enable it to contribute to a better understanding of the interactions between science, technology and society, in general, and of the complexity nuclear technology assessment in particular. Finally, and most important from a broader societal perspective, we argue that the self-critical character of the research and its willingness to see interaction with society *as part of the research itself* renders it 'by design' with credibility and robustness in a socio-political environment often characterised by controversy. In this sense, the research has the potential to contribute to an advanced form of societal decision-making that would be prepared to move beyond controversy, and would aim to seek societal trust by its inclusive and deliberate method, rather than by the envisaged or promised outcome.

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