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Research and Higher Education: A Disposable Part of Fundamental National Infrastructure

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Abstract

The electricity from the nuclear fission is abundant and competitive low carbon energy having one of the lowest impacts to the public health and environment. As such, the nuclear energy could immediately provide significant contributions towards the neutralization of the threats caused by the climate changes. This has been made possible through the substantial and long term efforts of the nuclear industry to sustain and improve the safety of the nuclear power plants. These efforts were systematically supported and sometimes also lead by the competent regulatory authorities and academia worldwide, and over the years resulted in unparalleled levels of stability and maturity.

Unfortunately, the dwindling public acceptance has recently become one of the major challenges that face the nuclear industry. On one hand, the very low impact of the nuclear energy to the public health and environment is undoubtedly and thoroughly supported by the available scientific and technical knowledge. On the other hand, the public – especially in the postindustrial societies – tends to disagree, more so with the information provided by the regulators and industry. A recent public opinion poll in the EU indicated that in the questions of nuclear safety people trust scientists much more that the regulators, government, media and industry.

Yet, both the regulatory authorities and the industry in some countries seem to be progressively losing interest for intense cooperation with the higher education and research establishments. Indeed, the already achieved and unquestionable high maturity and stability of the industry and regulators might give rise to a perception that further research cannot bring much added value to the safe operation of the plants and that higher education might be fully substituted by professional training. Such perception may be easily augmented by the economic recession. Ultimately, it might lead to a severe deterioration of the independent nuclear safety related research and higher education, which is considered a fundamental national infrastructure for nuclear safety.

The paper argues that the nuclear energy may improve the public trust significantly and at the same time improve the safety record by a much stronger commitment towards the science based decision making in the industry and the regulatory organizations.

Keywords:	Higher education, Research, Nuclear safety, Nuclear energy, Critical infrastructure

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1. Introduction

Access to sufficient, environmentally acceptable and affordable power sources might well be one of the most important challenges that the humankind will have to solve within a few decades.

The electricity from the nuclear fission may contribute significantly to the solution of this challenge. It is considered to be abundant and competitive low carbon energy having one of the lowest impacts to the public health and environment [1]. This has been made possible through the large and long term efforts of the nuclear industry to sustain and improve the safety of the nuclear power plants. These efforts were systematically supported and sometimes also lead by the competent regulatory authorities and academia worldwide. It is therefore not surprising that the nuclear energy, nuclear industry and nuclear regulators have over the years reached unparalleled levels of stability and maturity.

One of the key remaining challenges for the long-term success of the nuclear energy (and industry in particular) is the dwindling public acceptance. The very low impact of the nuclear energy to the public health and environment, and maturity and stability of the industry, is thoroughly supported by the available scientific and technical knowledge [1]. The public opinion, especially in the postindustrial societies, does not seem to acknowledge this. This may have fundamental consequences for the future of the nuclear energy, as shown for example by the accelerated phase out of nuclear power in Germany following the accident in Fukushima Dai-ichi in 2011 [2]. It should nevertheless be mentioned here, that as far the questions of nuclear safety are concerned, the European public opinion trusts scientists and researchers much more than governments, media, regulators or industry [3].

Research and education have been in the forefront of the development and implementation of the commercial nuclear power and are recognized as fundamental and necessary national infrastructure for nuclear safety [4-6]. The interest for intense cooperation with the higher education and research establishments may be however dwindling due to a fact that the maturity of the technologies available, industry and the regulatory organizations, is nowadays increasing through accumulated operational experience much more that through new research findings. Examples of cases, where the dwindling independent nuclear safety related research and higher education has been noted, include [7-10]. Examples describing actions being taken to strengthen and intensify the dwindling research and education include [11-14].

Indeed, the indisputable maturity and stability of the industry and regulatory organizations might give rise to the possibly detrimental perception that further research cannot bring much added value to the safe operation of the existing plants, and could be, for example, fully substituted by the operational experience. Another harmful perception might be that the higher education can be fully substituted by professional training. Such hazardous perceptions may be easily augmented by the decision makers, being overwhelmed with more urgent problems, such as for example economic recession. Ultimately, such developments might lead to a severe deterioration and termination of the independent nuclear safety related research and higher education, and therefore to the disappearance of the fundamental (critical) national infrastructure.

Fortunately, we are not yet aware of any incidents which would be directly caused by the deterioration of research and education. The paper therefore revisits some examples of industrial incidents caused by the deteriorating infrastructures, including hardware, safety culture and design bases, and develops some parallels between theses infrastructures.

The main aim of the paper is to consolidate possible concerns that might be caused by the deteriorating infrastructures and to explore the potential of nuclear energy to improve the public trust significantly and at the same time improve the safety record by a much stronger commitment towards the science based decision making in the industry and the regulatory organizations.

2. Examples of deteriorated infrastructures

The basic facts in the examples below are taken from the official reports or published literature. The deterioration of various infrastructures was undoubtedly at the core of the causal relationships leading to incidents and accidents discussed hereafter. Some degree of interpretation beyond the data given in the reports, or perhaps limited use of anecdotic evidence, have been used for better illustration of the possible causes, consequences and missed potential for avoiding of the infrastructure deterioration.

2.1. The Ontario Hydro meltdown in 1997

Let us start with the well-known example from the nuclear industry. In 1997, the top management of the Ontario Hydro Nuclear (Canada), one of the largest nuclear power plant operators on the planet with 19 nuclear units at the time, ordered an internal investigation. The team of external auditors recruited mainly from the US utilities was asked to provide "brutally honest" insight in the overall performance of the company. The set of issues under scrutiny included managerial leadership, culture and standards, people and performance, processes and procedures, plant hardware and design, organization and resources and labor relations.

The findings declared the status of the reactor operated by the Ontario Hydro Nuclear as minimally acceptable. The fundamental problems detected included for example "lack of authoritative and accountable managerial leadership", "the ability to take corrective actions is inhibited by an insufficiently detailed understanding of the standards and practices required to achieve excellence in nuclear operations" and "There is no real independent evaluation of proposed operations by people not directly involved in formulating the planned actions". The proposed solutions involved for example "a new approach to the culture, structure, and management" and "a rethinking of employee skill mixes and the regulatory process".

As a consequence, seven out of nineteen units were shut down immediately, some of them permanently. The remainder underwent up to two decades of painstaking improvements in hardware and in the culture. More details are available in the report [15].

One could safely say that such events could only be result of a deteriorating safety culture, mainly within the middle management, the softest form of the essential infrastructure for safe nuclear power. Some almost randomly selected citations from the report [15] in Table 1 and remarks from the persons involved [16] in Table 2 clearly confirm the severe deterioration of the safety culture. Fortunately, this has been recognized and acted upon by the senior management before the development of any serious incidents.

Table 1: Some remarks from the report

Employees lack a questioning attitude.
Decisions are dominated by a production mentality and managers feel excessive pressure to continue planned evolutions.
At times, personnel cannot comply with the established processes or procedures.
Serious shortages of key management, supervisory and some technical skills exist…
Design basis documentation is not accurately maintained.
The practice of offering critical services, such as training and engineering, on a "fee for service" basis has created an attitude that the groups providing the service are not a part of the team.

Table 2: Some remarks from the persons involved in the process [16]

"The issue of culture is that nuclear tries to keep everything confined within it. [They] won't tell anybody anything. That's not just the Canadian culture, it's the nuclear culture." ***Carl Andognini***
"Good teams can turn bad over 10 years if they're not self-checking and probing." ***John Zwolinski***
"We've been telling you that for a number of years. Over and over again, sir." ***Maurice Brenner***
"There's people in management that shouldn't be in management and they don't want to be in management, but it's the only way they can get more money." ***Carl Andognini***

2.2. Broken rail causing train derailment 2000

We should avoid the "nuclear culture to keep everything confined in nuclear", identified in the preceding section, and look into experience from the non-nuclear industries.

On 17 October 2000 the train traveling from London Kings Cross to Leeds derailed south of Hatfield Station. At the time of derailment, the train was traveling with the velocity between 185 and 188km/h. There were 170 passengers and 12 staff on the train. As a result of the derailment, four passengers were killed and over seventy were injured, four among them seriously.

The immediate cause of failure was the fracture and subsequent fragmentation of the rail. The rail failure was due to the presence of multiple and pre-existing fatigue cracks in the rail (rolling contact fatigue). The investigations showed that the company in the role of the "infrastructure controller" did not manage properly the maintenance of the tracks. To some extent, the inability to manage the maintenance was caused by the fixed price contracts, which were part of the privatization process in 1994 and could not be influenced by the senior employees of the "infrastructure controller".

Changes in the regulation have been introduced after the investigation to clarify the duties of the "infrastructure controller" and to facilitate the faster investment in the deteriorated infrastructure. More details on the accident investigation and follow-up measures are available in [17].

We should note here that the privatization of the railway system in the UK in the beginning of the 1990's included the splitting of the railway system into infrastructure (tracks, signalization) managed by the "infrastructure controller" and multiple train operators (wheels). Before the incident, the tracks and the wheels were part of the same business unit, and the management of ageing of both wheels and tracks was coordinated within this business unit. Privatization and splitting the wheels and tracks into different business units also disentangled the responsibility for the safety of tracks and wheels into different business units. In addition, the function of the top management of the railway system was dissolved into a set of now competing middle managers (infrastructure, traffic, …) and the regulator should have taken over the efficient management of the competing middle managers. After some incidents and accidents, the one at Hatfield being among the most serious, an efficient regulatory action brought the management of wheels and tracks again under a single control.

2.3. The closure of San Onofre nuclear units in 2013

The steam generators in two nuclear units operated by Southern California Edison were replaced in 2009 and 2010, respectively. Serious vibrations of the steam generator tubes, also resulting in a premature leak after one year of operation, prevented both units from reaching full power after the replacement and finally, through economic analysis, led to permanent shutdown of both units in 2013.

In a recent report by World Nuclear News [18], the US Nuclear Regulatory Commission (NRC) blames the tube vibrations to the faulty design of the replacement steam generators. The faulty design was a consequence of poor documentation of the design changes made in the original steam generators, which were not properly reflected in the plant's documentation, especially final safety analysis reports. The neglected duty of the operator was to timely reflect the changes of the plant in the final safety report. This resulted in (1) faulted design bases for the replacement steam generators and (2) in the fact that the design of the new steam generators did not pass the review and approval of the regulator prior to replacement. The regulator on the other hand neglected the duty to oversee if the plant is keeping the design bases in the final safety analysis report up to date. Also, the regulator acknowledged a regulatory oversight leading to the replacement of steam generator without the review and approval from the regulator.

The appropriate regulatory oversight and properly managed design bases can be safely considered a part of essential infrastructures. In the example above, both regulatory oversight and the design bases degraded over time, resulting in a much premature closure of two nuclear power plants and huge economic loss for the operator.

It shall be reiterated here that both infrastructures (design bases, regulator) had to fail at the same time to arrive at the closure of the both plants in this case. Proper and systematic oversight would most probably stimulate the operators to keep the design bases up to date. And, accurately updated design bases would certainly enable proper design regardless of the subsequent review and approval by the regulator.

The immediate responsibility probably again goes to the middle management with the operator and regulator for the daily mismanagement of the infrastructural activities. The top management (again with both the operator and regulator) could have prevented the incident by paying proper attention to the management of the infrastructural activities.

2.4. Summary

At least four parallels can be found in all three examples discussed in the preceding section:

- Severely deteriorated infrastructures caused rather severe consequences (rails, safety culture, design bases and regulatory system).
- Middle management responsible for the infrastructure did not recognize the initiation and progress of the deterioration of the infrastructure.
- Supervisors (either top management or regulators) did not provide access to sufficient resources, knowledge and/or adequate supervision.
- The deterioration of the infrastructures, if detected on time, could have been preventable with the knowledge existing before the incidents, e.g. without further research.

It is fair to say that much of the above boils down to the ways of management at different levels, to the interactions between different organizational levels inside and between different stakeholders, and finally, to the access to the already available knowledge residing elsewhere. These are, in general, interplay of different corporate cultures. This is further discussed in the subsequent section.

More detailed investigation of these examples and the parallels - especially in the view of the management theory - is clearly beyond the scope of this paper.

3. Interplay of (corporate) cultures

The interplay of different (corporate) cultures is discussed in this section. To this end, the basic concepts of culture, safety culture, and corporate cultures are briefly introduced. A short discussion of the concept of safety research is followed by a summary of a recent study outlining possible obstacles in communicating the scientific facts. The section is closed by a summary identifying the basic elements of (corporate) cultures that could contribute to the development of incidents discussed in the preceding section.

3.1. Culture, Corporate Culture, Safety Culture

The notion of nuclear safety culture emerged after the accident in Chernobil and has received huge attention in the literature. Indeed, concept of culture usually includes (nearly) every aspect of the life of an individual in a group and, among others, gives the individuals the sense of stability and predictability. We will rely here on the fairly recent and refreshing discussion on Ethics, risk and safety culture by Kastenberg [19]. He assumes that:

(1) *Culture can be defined as the integrated pattern of human behavior that includes thought, speech, action and artifacts on human capacity for learning and transmitting knowledge to succeeding generations.*

(2) *Culture gives rise to a society's values, assumptions and beliefs. Hence culture is concerned with the act of developing the intellectual and moral facilities, especially by education.*

(3) *Culture itself, arises out of a context or paradigm that defines an individual's or a society's cultural conditioning. Hence an individual's or a society's values, ethics and morality are contextually or paradigmatically dependent.*

(4) *For the most part, societal conditioning and the context or paradigm from which it arises is implicit, i.e. cultural conditioning resides in the unconscious (emotive) and sub-conscious (mental). The conscious aspects of cultural conditioning that are cognitive, resides in the mental.*

(5) *Safety culture is "designed" within the larger societal cultural context that is "developed organically". Hence safety culture is affected by the larger culture, usually in an implicit way, as an overlay to achieve a specific goal.*

(6) *When the societal culture runs counter to the demands of safety culture, and is left implicit, it can shift from underlying to undermining.*

(7) *Approaches to quantifying and managing the risk of (…) accidents before they occur, as well as approaches for emergency preparedness and response should an accident occur, are based on the "safety culture" of the individuals and the organizations/institutions that comprise the nuclear establishment.*

(8) *In order to explore the safety culture of a host nation with respect to nuclear power, it is essential to understand the context or paradigm out of which cultural conditioning, and hence its ethics and technology arise*.

It is clear from above that the safety culture of every individual is of paramount importance for the timely detection and neutralization of the known and potential threats. At the same time, the safety culture of every individual is deeply influenced by his/her assumptions, beliefs, education, ability for critical thinking, obedience, etc. Let us reiterate here that individual's assumptions, beliefs, education, ability for critical thinking, obedience, etc., may be also be most heavily influenced by the culture of the society at large.

This seems to be consistent with the words of the Chairman of the Independent Commission reporting to the Diet of Japan after the Fukushima Dai-chi accident, who has put a significant part of the blame for the accident on the Japanese cultural features such as "reflexive obedience, reluctance to question authority, devotion to 'sticking with the program', groupism (collectivism) and insularity" [20].

The interference between the safety culture and the culture of the society may well be illustrated by the concepts of experience and education. The culture of the society has developed mostly on the experience of numerous preceding generations and only slowly takes on influences from research and education. Safety culture on the other hand has been designed through research and education and progresses rather fast with influences from experience and also further research and education. As a consequence, there could be many successful safety cultures within a single culture of a society.

Different organizations also developed different corporate cultures. Again, many successful safety cultures might reside within a single corporate culture.

It is safe to conclude that excellent safety culture requires active participation of all individuals and organizations involved in the safe utilization of nuclear energy. Learning from one's own mistakes shall be systematically accompanied with learning from best available scientific knowledge and operational experience.

3.2. Culture research

Perhaps, former United States Secretary of Defense, Donald Rumsfeld said it best [19]:

"Reports that say something hasn't happened are always interesting to me, as we know, there are known knowns. There are things we know we know. We also know there are known unknowns. That is to say, we know there are some things we do not know. But there

are also unknown unknowns, the ones we don't know, we don't know."

Technically, a safety philosophy (e.g., defense in depth) can account for two types of uncertainty: aleatory (random variations and chance outcomes in the physical world) and epistemic (lack of knowledge about the physical world). More research can reduce epistemic uncertainty, however, aleatory uncertainty can only be estimated better, but not reduced with more research [19].

Safety research is also needed to put additional light on indeterminacy (e.g. a unique initiating event leading to accident sequences that may take many paths) and a high level of ambiguity (i.e., non-unique, alternative or multiple legitimate interpretations based on identical observation or data assessments). Ambiguity may come from differences in interpreting factual statements about the world or from differences in applying normative rules to evaluate the state of the world.

Finally, the science and research provide the only available tool to investigate the realm of the unknown-unknown [19].

3.3. Communicating and accepting scientific facts

Not all facts accepted by the scientific community are accepted as facts by the society at large. Examples include the nuclear power having the lowest impacts to the public health and environment and the threats posed by the climate change on the planet. A very recent study attempted to shed light more light on "*The failure of widely accessible, compelling science to quiet persistent cultural controversy over the basic facts of climate change is the most spectacular science communication failure of our day*" [21].

The main conclusion seems to be "*The source of the climate-change controversy and like disputes over societal risks is the contamination of the science communication environment with forms of cultural status competition that make it impossible for diverse citizens to express their reason as both collective-knowledge acquirers and cultural-identity protectors at the same time*." [21]

Kahan [21] argues that this is caused by »*the dual nature of human reasons as collective-knowledge acquirers and cultural-identity protectors. Just as individual photons in the double-slit experiment pass through "both slits at once" when unobserved, so each individual person uses her reason to simultaneously apprehend what is collectively known and to be a member of a particular cultural community defined by a set of highly distinctive set of commitments…*

…Moreover, in the science of science communication as in quantum physics, assessment perturbs this dualism. The antagonistic cultural meanings that pervade the social interactions in which we engage citizens on contested science issues forces them to be only one of their reasoning selves. We can through these interactions measure what they know, or measure who they are, but we cannot do both at once.

…Without question, this style of reasoning is collectively disastrous: the more proficiently it is exercised by the citizens of a culturally diverse democratic society, the less likely they are to converge on scientific evidence essential to protecting them from harm. But the predictable tragedy of this outcome does not counteract the incentive individuals face to use their reason for identity protection. Only changing what that question measures—and what answers to it express about people—can."

Now, for an individual member of the society, it seems quite natural to give clear priority to the reasoning within his or her social group than to the knowledge he or her acquired from science (and education). In simple terms, the communication between "nuclear" and "non-nuclear" may be easily dominated by the affiliation over the scientific facts. A possible way out, as suggested by Kahan, is to disentangle the affiliations and the scientific facts.

Would this also apply for the communication between different nuclear stakeholders?

3.4. Summary

The accident and incidents discussed in the preceding section were in general caused by the interplay of different corporate and safety cultures. As a consequence, certain approaches of the management were implicitly or explicitly accepted, regardless of the fact that the risks involved were or could be classified as unacceptable.

In particular, the communication of the knowledge available did no work beyond the groups of peers, e.g., between different levels of management within the company or between different organizations. For example, the management of the "infrastructure controller" involved in the rail accident was aware of the insufficient resources available, but most probably failed to efficiently communicate this to the regulator. It is noted here that every communication is a two way process, in which both sender and receiver share the responsibility for the success.

It is further noted that the successful communication between members of different cultures or groups may depend much stronger on the affiliations of communicators than on the scientific relevance of the information. A culture or group, which is more open and transparent to the "nonmembers", may therefore improve the probability of successfully conveying the message to the members of the cultures, which have not yet assimilate this particular message.

Occasional failures to communicate relevant facts between different nuclear stakeholders is at the forefront of nuclear incidents discussed above [16, 18] and also much more studied Fukushima Dai-ichi accident [20]. It is even more natural to expect that such communication failure exists also between nuclear stakeholders and the general public. Appropriate changes needed to improve internal and external communication might also cause the redesign of the existing safety cultures and affiliations with them.

A good starting point would be to embrace the science and higher education organizations in the corporate safety cultures through strong partnerships and exchange of staff. This may at the same time improve the communication with public and at the safety records through a much stronger commitment towards the science based decision making in the industry and the regulatory organizations.

4. Conclusion

The electricity from the nuclear fission may contribute significantly to the solution of the challenge of global warming. It is namely considered to be abundant and competitive low carbon energy having one of the lowest impacts to the public health and environment. This is thoroughly supported by the available scientific and technical knowledge. Unfortunately, the public opinion, especially in the postindustrial societies, does not seem to acknowledge these scientific and technical facts.

A significant part of the technical success of the nuclear energy was to develop specific corporate cultures, sometimes also called safety cultures. Examples of incidents revisited in the paper indicate, that within these safety cultures there is a potential for poor communications of technical and scientific facts even between different corporate groups or between different nuclear stakeholders.

Recent research in the science of science communication indicated that the affiliation with cultures and/or groups may significantly impair or annihilate the communication of scientific facts. This certainly gives additional rise to the potential risk that affiliations with different cultures of nuclear stakeholders might bring to the safety record of the industry and public perception. Appropriate changes needed to improve internal and external communication might also cause the redesign of the existing safety cultures and affiliations with them.

A good starting point would be to embrace the science and higher education organizations in the corporate safety cultures through strong partnerships and exchange of staff. This may at the same time improve the communication with public and at the safety records through a much stronger commitment towards the science based decision making in the industry and the regulatory organizations.

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