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Reexamining the Ethics of Nuclear Technology

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Abstract This article analyzes the present status, development trends, and problems in the ethics of nuclear technology in light of a possible revision of its conceptual foundations. First, to better recognize the current state of nuclear technology ethics and related problems, this article focuses on presenting a picture of the evolution of the concepts and recent achievements related to technoethics, based on the ethics of responsibility. The term 'ethics of nuclear technology' describes a multidisciplinary endeavor to examine the problems associated with nuclear technology through ethical frameworks and paradigms. Second, to identify the reasons for the intensification of efforts to develop ethics in relation to nuclear technology, this article presents an analysis of the recent situation and future prospects of nuclear technology deployment. This includes contradictions that have aggravated nuclear dilemmas and debates stimulated by the shortcomings of nuclear technology, as well as the need for the further development of a nuclear culture paradigm that is able to provide a conceptual framework to overcome nuclear challenges. Third, efforts in the field of nuclear technology ethics are presented as a short

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overview of particular examples, and the major findings regarding obstacles to the development of nuclear technology ethics are also summarized. Finally, a potential methodological course is proposed to overcome inaction in this field; the proposed course provides for the further development of nuclear technology ethics, assuming the axiological multidisciplinary problematization of the main concepts in nuclear engineering through the basic ethical paradigms: analytical, hermeneutical, and poststructuralist.

Keywords Ethics · Responsibility · Nuclear technology · Holistic approach · Engineering · Dilemma · Challenges

Introduction to the Ethics of Technology

The Status of Technical Theory

The unprecedented growth of human technological power has become the defining characteristic of contemporary global order. Moreover, this fact attracts well-founded concern, not only because of a continuing series of manmade disasters, but also for more unobvious reasons. Scientific and technical progress has allowed humanity to prevail over nature—at least to a degree. On the face of it, it appears that people have behaved quite reasonably in using the power of nature against itself. However, this process has had unexpected consequences.

First, technology has increased people's strength and allowed them to project this new strength against one another. Mankind now faces the threat of self-annihilation. Second, technical expansionism has considerably changed the position of humankind in the world. If the anthropomorphous center of the world previously was clearly bounded in space, its boundaries have now become vague. According to numerous philosophers, people have carelessly objectivized their original anthropomorphous traits in the alien natural world. In other words, people are losing their authenticity. When humans create, they constantly test new limits, something that is potentially dangerous. Reflecting on this question, philosophers have concluded that an adequate response must consider ethics. People must turn to ethics when facing dangerous situations. Thus, it seems necessary to discuss the current problems related to technology and the fate of humanity, and as such, technical sciences should be the primary focus of such a discussion (Kanke 2003, 2010).

Our reflection on a problem should proceed from a scientific interpretation of the object of study. Philosophers frequently speculate on technics, yet in doing so they disregard the technical sciences. We believe that this approach leads to a metaphysical deadlock.

So, what is the nature of the technical sciences, and what are their characteristics? First, contrary to common belief, technical science differs significantly from natural science. Kötter said that technical problems are of the 'purpose—means', while technical rationality is a specific purposeful rationality (Kötter 1986). Having summarized a substantial amount of the philosophical literature related to technical sciences, Gorokhov concluded the following: ‘In contrast to the law of nature that defines the form of possible events, technical regulations are standards. While statements expressing laws may be more or less true, regulations can be more or less effective’ (Gorokhov 1995).

We believe that Kötter and Gorokhov were correct in characterizing the specificity of the technical sciences. However, their viewpoint can be made more precise. It is essential that purposeful rationality suggests, one way or another, the involvement of so-called ‘values’ in philosophy. The ‘purpose–means’ link of Kötter should be modified to represent a ‘value–purpose–means’ link. But in what form are values presented in the technical sciences?

In any pragmatic science, values as concepts appear in the form of variables. In the technical sciences, values are commonly referred to as parameters or characteristics. Vehicle speed, engine efficiency or engine power, computer memory space, and ship cargo capacity are all parameters whose optimal values are of interest to their end user. It is said that a technical science is intended to improve parameters, which alone already suggests the pragmatic content inherent in this method. In this context, technical regulations are normative. However, they are not always standards, rather only when established by an authority as a general standard. This is not always the case however. In the developmental stage, values cannot be standards by definition.

Gorokhov contrasts the efficiency of technical provisions with the truth of natural science laws. In the natural sciences, it appears as the ideal of descriptiveness, while in the technical sciences it is efficiency. Thus, the concepts involved in technical sciences are value-parameters, whereas the concept of truth and the method for its identification are pragmatic. Thus, the technical sciences should refer to the type of pragmatic disciplines. In the pragmatic sciences, ethical standards result from examining the problem of seeking the most efficient solutions (Kanke 2009, 2013). With respect to basic technical disciplines, technoethics serve as a meta-science,[1] and is endogenous in relation to technical sciences. We clarify this deduction later.

Let us assume a situation involving a discussion of the design of a new generation nuclear power plant (NPP). Compared with their predecessors, new generation NPPs should be more reliable, environmentally friendly, and cost efficient. However, these improvements cannot be achieved simply using the available technical science. Instead, the available knowledge should be subjected to thorough methodological analysis to identify technoethical issues, in this case in relation to nuclear technology.[2] Successful experts in the field of nuclear energy should be committed to moral actions, and deserve to be accused of amorality should they fail to exhibit such a commitment. Crucially, experts should be ethical because of, rather than in spite of, their professional knowledge. Moral appeals that do not account for the peculiarities of professional work are harmful.

[1] Metascience is a theory of science or science about science (Allwood and Bärmark 1999).

[2] The authors use the term ‘ethics of nuclear technology’ to describe the analysis of ethical issues related to nuclear technology, so as to overcome nuclear dilemmas and structure nuclear debate, but not the term ‘nuclear ethics’, which is widely used to indicate a field of academic and policy-relevant study that examines the ethical problems associated with nuclear warfare, deterrence, arms control, and disarmament (Nye 1986).

An appeal to technical science enables technics to be defined as a set of artifacts (from Lat. *arte*—artificially + *factus*—created) interpreted in terms of parameters. The distinction between technical artifacts and works of art lies in their interpretation using technical parameters rather than aesthetic values. The above discussion of technoethics, while identifying its urgency, does not seem sufficient to define technics as a global factor in human life and activities. In this context, while further thematizing ethical problems related to the technosphere, it seems reasonable to consider how technics have been interpreted by leading philosophers.

Technoethics and the Ethics of Responsibility

'Man can do more than he has a right to' (Lenk, H., Ropohl, G. (1993). Technik zwischen Koennen und Sollen.). This imperative applies to a number of human activities, but especially to the technical sphere. Thus, there exists a critical problem with regard to how human technical activities interface with ethics. As noted by Lenk and Ropohl, this problem remains unsolved (Lenk, H., Ropohl, G. (1993). Technik zwischen Koennen und Sollen.). Therefore, what is the place of ethics in the field of technical sciences?

First, it is necessary to realize that the enormous technical power of humans, which occasionally has disastrous consequences, has led to the conviction, most energetically expressed by H. Jonas, that it is necessary to develop the ethics of responsibility (Lenk 1986; Lenk, H., Ropohl, G. (1993). Technik zwischen Koennen und Sollen. Jonas 1979; Mitcham 1995). Intuitively, it seems evident that people should regulate their conduct. However, what this means conceptually remains unanswered. In this context, a study conducted by a group of German philosophers is particularly notable (Lenk, H., Ropohl, G. (Hg.) (1993) VDI-Ausschuss: Grundlagen der Technikbewertung). In evaluating technics, this study suggested a reliance on the following eight values: (1) personality development, (2) social development, (3) human welfare, (4) public health, (5) technical safety, (6) environmental-friendliness, (7) technical efficiency, and (8) operational suitability. (Some of these eight values contradict one another).

Thus, the pursuit of increased safety and ecological comfort is associated with decreased technical efficiency and human welfare. According to the logic of the German philosophers above, the main value is personality development, which together with social development comprises a single organic whole. In this connection, justice is a critical fundamental value.

The eight relevant values are distributed among different disciplines: development of personality and society relate to the humanities; human welfare and technical efficiency relate to economics; public health relates to medicine; environmental quality of life is discussed in relation to ecology; and operational suitability—simplicity, reliability, accuracy, performance, efficiency, and safety—relates to the technical sciences. Thus, distributing the values among the different sciences, the approach developed by the German authors suggests that interdisciplinary links should be established to realize the ultimate success of environmental activities.

However, establishing such links among disciplines with different axiological weights is challenging. The principle of responsibility proposes an optimal combination of numerous values (which are delegated not in material terms but instead in the form of signs) for technical artifacts. This situation is rather multidimensional, as separate varieties of ethics—technical, political, economical, and ecological—reflect one another in a semiotic relationship. The values of some disciplines represent preferences valid in other concepts. The principle of responsibility combines all types of ethics in a single harmonious concept, and includes non-apparent links such as coordination and subordination. Defining these connections and ensuring their operation are the tasks of meta-science, which brings together ethics and the sphere of human technical activities. Besides, the principle of responsibility offers not only the harmonious synthesis of different values, but also their continuous transformation for the future.

If people do not appeal to meta-science, they can find simple means to implement the ethics of responsibility. According to different ethical codes, engineers and technologists attempt to be honest, fair, and loyal to their customers, to coexist harmoniously with their workmates, to exhibit honesty in general, and to seem to uphold freedom and human happiness. It is sometimes argued that an engineer's morality can be based on the Sermon on the Mount. Nevertheless, a sharp distinction is usually drawn between universal human virtues (such as justice and honesty) and the professional virtues (such as carefulness and diligence) of engineers and technologists.

From a conceptual viewpoint, codes of ethics do not stand up to criticism. Such codes ignore the diversity of human values and are usually presented in the form of virtues, but values treated as concepts cannot be limited to personality traits. Undeniably though, despite their defects, codes of ethics are useful to cultivate because they can contribute to making engineers and technologists more socially responsible. However, no single remarkable example exists where the engineering community has provided the public with an advance warning of the undesirable effects of using its technologies. It must be noted though that nobody has the right to evade their personal responsibilities. We believe that without thoroughly understanding the axiological character of the technical sciences it is impossible to ensure the complete success of technical activities.

So far we have discussed technoethics in general terms. Now, we shall turn to the moral questions surrounding a currently important technical discipline—nuclear engineering.[3] Specifically, we look at the ethics of nuclear technology.

Dilemmas and Debates on Nuclear Technology

Current State and the Prospects of Nuclear Technology Deployment

Through its 70-year history of development, nuclear power has reached the point where it can be considered a mature industrial technology (Andrianov 2014;

[3] Nuclear engineering is a branch of engineering that involves the application of nuclear fission, fusion, and ionizing radiation. It also includes the design and maintenance of systems and components of nuclear and other related technologies, as well as the study of associated processes (e.g., neutronics, heat transport and thermodynamics, and nuclear fuel behavior) and problems (e.g., safety, radioactive waste disposal, and nuclear proliferation).

Murogov 2014). The possible peaceful applications of nuclear technologies have been significantly extended, and currently include power engineering, medicine, agriculture, industry, and space. Moreover, recent years have witnessed a tendency towards an increased awareness of the significance of nuclear power as a stable and efficient energy source that is generally accompanied with the promotion of associated investment and innovation. Simultaneously, the past 10–15 years have seen a sharp decline in the growth of nuclear power generation capacity.

The reason for this situation lies in the termination of state subsidies and guarantees to support nuclear power, the introduction of market dynamics to the electrical power industry, the low competitiveness of newly built NPPs, and the negative attitudes of the Western public and policy-makers towards the further development of nuclear technologies. Owing to these tendencies, opinions on nuclear power have become increasingly polarized, with the public (including policy-makers) clustered at one extreme and the representatives of the nuclear sector clustered at the other.

The majority of policy-makers, including those from nuclear countries, non-governmental ecological organizations, and some other social movements, believe that the conclusions and recommendations of nuclear specialists cannot be trusted and hence oppose nuclear power in both the immediate and medium-term futures.

In contrast, most representatives of the nuclear sector, whether involved in science or industry, strongly believe that nuclear power is both feasible and necessary. Specifically, they perceive nuclear power as the only solution to the problem of providing humanity with a sustainable energy supply, particularly given the various global and local ecological problems.

In this respect, it is imperative that we comprehensively analyze the current contradictory positions concerning the future role of nuclear power, identify the reasons for the ambiguous attitudes towards it, and search for a reasonable compromise that provides nuclear technologies a defined and restricted role that incorporates the views of all concerned parties. Nuclear power has been intensely controversial for more than half a century and the successful resolution of this controversy is considered unlikely. The current state of nuclear power thus clashes with the consciousness of both experts and the public, fully reflecting the disagreements that arose during the global expansion of nuclear technologies, between the concepts of pioneers and practical solutions. This analysis cannot be realized without an analysis of ethical issues, and the ethics of nuclear technology should be among the tools used in such an analysis.

Contradictions in the Development of Nuclear Technologies

Nuclear technologies are inseparable from associated threats and risks that could, at the very least (if not acceptably mitigated), considerably restrict their potential usage. Experts note five significant problems that attract public concern, which in turn constrain the large-scale development of nuclear technology: safety, the threat of unauthorized nuclear material and technology proliferation, radioactive waste management, commercial efficiency, and limited natural nuclear fuel resources.

These problems are interconnected, and are also long-term, global, conflicting, and dynamic. Separate problems are exacerbated depending on external factors that can determine the direction of development. Conflict manifests not only among various factors, but also because specific measures may decrease long-term risks while increasing short-term ones. Such interdependences confirm the importance of an integrated approach to elaborate certain decisions, and demand that the impacts of specific decisions on the system as a whole are fully considered.

Cotemporaneous public awareness of the huge potential and actual risks associated with nuclear technologies results in uncertain social attitudes towards their development and deployment. This imposes obligations on the expert community to develop appropriate risk management measures for the operation of nuclear and related technologies.

In this regard, serious efforts have been made and baseline nuclear technology requirements have been formulated at the International Atomic Energy Agency (IAEA) level. These should be well-resourced and low-waste-oriented in the long term, remain cost-effective, and support adequate safety and reliability. Furthermore, they should guarantee both proliferation resistance and the reliable physical protection of nuclear materials.

Despite the wide range of both nuclear reactor and nuclear fuel cycle (NFC) technologies demanding comprehensive analysis, as well as an awareness that nuclear technology should meet the above baseline requirements, the current quantitative criteria for the selection of a long-term development strategy and promising technological solutions are not clearly defined. This does not allow for either the formation of a policy to develop nuclear technologies, which would be balanced with respect to various benefits and risks, or the realization of agreed strategic and tactical decisions regarding each problematic area.

No standard methodology presently exists to evaluate the efficiency and risks in every problematic area related to the development of nuclear technologies. This area is characterized by the multi-faceted and dynamic nature of the problem, together with uncertainty regarding the initial data (Andrianov 2012). Given these circumstances, it is necessary to continuously improve and expand efficiency and risk evaluation methods, as well as to create a relevant methodological foundation based on ethics for nuclear technology. The following details the basic contradictions that constrain the development of nuclear technology (Andrianov 2014; Murogov 2014).

1. Despite the potentially inexhaustible nature of the resource base offering the possibility that nuclear power could be compatible with sustainable development, the practical implementation of nuclear power remains based on thermal reactors utilizing mainly uranium-235 from relatively rich ores, the inferred reserves of which are less than those of oil and gas (Fortov 2009). The potential of vast uranium resources supplemented by the possible use of fast breeder reactors and thorium-based fuel cycles point to a future where nuclear energy can meet the constant demand. Sufficient nuclear fuel resources exist to meet current energy demands and those of future generations well into the future at existing and increased demand levels. However, using this potential will require considerable effort and investment

to develop new uranium mining projects and rapidly apply advanced technologies (NEA news No 20.2. 2002).

2. Despite recognizing the possibility to create inherently safe nuclear reactors, this concept was not fully implemented and resulted in a number of serious accidents, including those at Three Mile Island in the United States (1979), Chernobyl in the Soviet Union (1986), and Fukushima in Japan (2011) (Word Nuclear Association, Safety of Nuclear Power Reactors). According to a probabilistic safety assessment, the probability of accidents has reduced from 10^{-3} per reactor/year to 10^{-4}, but not to the desired levels of 10^{-6}–10^{-8}.

The Fukushima disaster involved serious accidents at four reactors and three storage facilities, a total of seven simultaneous severe accidents. Any reactor is vulnerable to accidents, and all statements regarding the design and construction of ultra-safe reactors are mere bluff. The term 'safe' should only be applied to a reactor designed in such a way that an accident will not negatively affect humans (such reactors are currently being developed). However, approximately 60 % of the 440 reactors operating today were commissioned before the Chernobyl accident. While these reactors have been improved in the wake of Chernobyl and other accidents, they are nevertheless outdated.

For a number of developing countries with insufficient oil and gas reserves, nuclear power is the only way to securely grow power generation. However, the 2011 accident in Japan provides the developing world, where nuclear power generation is considered a possible power generation option, a negative example of the scale the potential problems associated with this form of power generation can reach.

While new technologies are currently in development, the rate of development leaves much to be desired. For example, although significant progress is being made in China, where construction to date has been limited to well-tested reactor designs (such as WWER-1000), new evolutionary and innovative reactors are yet to be commissioned (e.g., Generation III + AP-1000 and EPR reactors and Generation IV fast reactors).

3. Despite the possibility of fully controlling and isolating almost all radioactive waste, the problem of the ultimate disposal of such waste remains unsolved. As of the end of 2005, while the total of spent nuclear fuel (SNF) worldwide equaled close to 276,000 tHM,[4] only 30 % was reprocessed. The remaining SNF is stored in at-reactor pools and away-from-reactor wet and dry storage facilities. Projections indicate that the cumulative amount of such spent fuel generated worldwide may exceed 440,000 tHM by 2020, with 320,000 in storage (International Atomic Energy Agency, Status and Trends of Nuclear Technologies).

4. Despite the nuclear non-proliferation regime created and accepted by most states, the expansion of nuclear technology around the world is such that it is impossible to fully control the black market in nuclear materials and technologies and to establish an international mechanism to prevent new states gaining possession of nuclear weapons (Andrianov 2011). Factors influencing the risk of proliferation include the growing number of countries that use nuclear energy, the

[4] Tonnes of heavy metals (tHM).

number of nuclear power plants, number of fuel cycle facilities and their nomenclature (first of all, uranium enrichment, SNF reprocessing), the circulation and transport of nuclear materials, and the volume of radioactive waste. Structural changes in the nuclear energy industrial complex (fuel breeding, use of breeder reactors, and small and medium-sized reactors for regional energy supply, SNF reprocessing, nuclear fuel recycling, and transition to closed NFC) also invert proliferation risk. Another risk is the development of nuclear power in currently non-nuclear countries that lack the preparation to manage nuclear technology (e.g., through participation in nuclear security and non-proliferation treaties). The abovementioned factors inevitably increase the proliferation risk.

5. Despite the anticipated nuclear renaissance, innovations such as closed NFC and plutonium breeder reactors that offer the possibility of large-scale and safe development of nuclear energy have not been commercially implemented. The problem of the aging of scientific and engineering personnel and the threat of loss of experience and knowledge are also of significant importance (Word Nuclear Association, Fast Neutron Reactors).

Statements about developing absolutely reliable and safe ('naturally' safe) technologies should sometimes be suppressed so as not to mislead decision-makers and the general public with regard to the objective parameters of a project.

6. Although nuclear power is considered a relatively 'pure' energy source that helps global technology impact the climate of the planet, present-day NPPs with thermal reactors are characterized by low efficiency values that increase 'direct' thermal environmental pollution to higher levels than those associated with various modern energy technologies.

The six issues listed above simultaneously demonstrate the potential of nuclear power as an advanced energy technology and limit the likelihood of its large-scale deployment. The lack of solutions to these problems has resulted in the failure to realize the desired rate and projected scale of nuclear power development, as well as promises regarding low-cost NPP-generated electricity (the average total plant cost has increased four-fold because of defense-in-depth design implementation). Thus, growing concerns related to radioactive waste and the threat of uncontrolled proliferation of nuclear materials and technologies have formed a significant stumbling block (Smil 2010).

Nuclear Culture

In reaction to the challenges and contradictions associated with the development of nuclear technology, culture has become increasingly important in all problematic areas, namely: safety, non-proliferation and security, ecology, and infrastructure. The sharing of best practices through nuclear culture is particularly important for countries new to the application of nuclear technologies. To address the problems of the effective prevention of misuse of nuclear technologies and materials, waste management, and resource utilization, it is essential to formulate a comprehensive package of technical, political, and institutional measures, accompanied by furthering the educational and ethical levels of staff involved in nuclear activities. Together these factors form the nuclear culture.

Naturally, progress and failures in the development of nuclear technology have included certain attempts to form a nuclear culture (International Atomic Energy Agency (2008a). Nuclear Energy Series No.7). The main objective of these activities is the creation of the methodological and conceptual foundations for a new integrated endeavor—a nuclear culture.

In this context, attempts have been made to support those activities that contribute to the creation of an international culture of responsible nuclear science and knowledge management, with a particular focus on the most 'sensitive' scientific areas. Nuclear engineering is the first priority for such considerations, taking into account the present status of the subject: sensitive technologies and knowledge dealing with dual use potential, specific legislation, nuclear materials and export control, international activity, and educational programs. As in the implementation of nuclear safety and security culture, it was recognized that this problem should be dealt with not only by regulatory authorities, but also by researchers, designers, managers, and operational and other staff. A similar path should be chosen in other areas of nuclear culture.

The formation of a nuclear culture requires the consideration of the ethics of nuclear technology. From now on we shall understand the ethics of nuclear technology as a multidisciplinary (or interdisciplinary, cross-disciplinary, and trans-disciplinary) endeavor that is focused on examining the problems associated with nuclear technology development via ethical frameworks and paradigms.

The Necessity for Ethics of Nuclear Technology

What Does Ethics of Nuclear Technology Mean?

Ethical problems involving the nuclear field involve both military and peaceful applications of the atom—nuclear weapons and nuclear power. The age of atomic weapons began on July 16, 1945, when the Americans first tested a nuclear weapon in Alamogordo, New Mexico. Nineteen days later, they dropped an atomic bomb on the city of Hiroshima in Japan. Five months after the explosion, the recorded number of victims totaled 140,000. Humanity entered the third millennium in possession of an arsenal of 32,000 atomic and hydrogen bombs, enough to destroy all life on Earth.

The beginning of the nuclear power era is usually associated with the commissioning of the first nuclear power plant in 1954 (in Obninsk, USSR). Because of the depletion of fossil fuel resources, nuclear power has recently gained ground. However, safety has also become a growing concern and in response, safety strategies have been redefined. A turning point in this regard was the Chernobyl catastrophe in April 1986. The aftermath of this event affected not only the residents of the Soviet Union, but also most of continental Europe, from Italy and Great Britain to Sweden and Norway.

In parallel with the construction of NPPs, nuclear facilities including reactors were also installed on transport vehicles, such as ships, and particularly submarines. This field has also witnessed severe accidents, with the after-effects remaining largely unknown. Furthermore, nuclear technologies were developed with notable haste. A real race occurred, especially between the United States and the Soviet Union, in the fields of nuclear weapons and nuclear power. When the relationship between these two rivals once again became amicable (only recently in the late 1980s), it became apparent that many crucial issues associated with the development of nuclear technologies remained unsolved. Examples included the problems of nuclear-waste storage and processing, the non-proliferation of nuclear materials and technologies, and issues related to resources, economics, and safety. We have here a dazzling example of improvidence—it is reminiscent of people electing to embark on a dangerous flight without first making any provisions to ensure a safe landing.

Advances in nuclear physics and engineering have allowed people to develop the capability to dispose of extremely powerful energy sources. However, the possession of this capacity may ultimately prove harmful, and this can be seen in the gradual spread of nuclear disasters across the planet. Simultaneously, many educated scholars have sought to answer the question: 'How to use the potential of ethics, and which ethics should be used?'

Mitcham rightly notes that nuclear technologies can apparently be justified on utilitarian grounds (Mitcham 1995), which seems to provide a good basis for the ethics of nuclear technology. However, this approach includes a significant difficulty that is generally ignored. The effectiveness of the utilitarian ethics depends on the field of its application. It is quite different when applied to dinner preferences than when applied to manage powerful energy sources. In the latter case, the benefit from ethics is valid only when it is seamlessly coupled with preferences regarding safety, risk, and responsibility. The ethics related to nuclear technology have matured through the conceptual development of these preferences, a fact that is not always recognized. Thus, we appeal to common sense ethics in relation to nuclear technology.

Generally, the development of ethics in relation to a specific technical field goes through several stages, and the ethics of nuclear technology is no exception. As a first step in developing the ethics of nuclear technology, we apply traditional ethical maxims, such as religious ethics (e.g., killing is forbidden by God) or consider the potential of deontic ethics. In such cases people rely on absolute imperatives. Thus, Granoff refers to the Golden Rule: 'In everything, do unto others as you would have them do unto you' (Granoff 2000). This means that actors, including individual countries, must not harm one another. However, exactly how to realize this lofty goal remains unclear. Second, we appeal to existing codes of ethics and develop an appropriate professional code. Third, we recognize the need for a detailed understanding of values based on refined technical concepts. The application of the last two items to specific examples is considered next.

Efforts Realized and Lessons Learned

Code of Ethics

Since June 2003, the members of the American Nuclear Society (ANS) have abided by an ethical code (its major axiological reference points are occupational integrity and dignity); the code is considered necessary to improve human welfare and to preserve the environment (the so-called Code of Ethics). The members of the ANS are committed to honesty, open-mindedness, and loyalty in their dealing with customers, and they continuously raise the bar regarding their competence and occupational prestige. Professional behavior is assessed in terms of following values: community safety, health, and welfare; timely public notification of possible negative consequences of planned actions; support of those guided by similar principles of behavior; only providing services that ANS members have competence in; publicity; continuous professional development; fair treatment of customers; fair competition with the producers of similar goods; condemnation of bribery and unauthorized coercion; and openness to criticism (Code of Ethics of ANS). Finally, ANS members commit to accept responsibility for their actions. The ANS Code of Ethics thus contains a promise to be motivated by a score of positive values, and refers to the ethics of responsibility as applied to human activities in the field of nuclear technologies.

Another example of good practice in the development of nuclear ethical codes is the IAEA's endeavor to establish a code of ethics for organizations operating nuclear facilities. This concerns the improvement of their performance by focusing on the ethics and professionalism of personnel at all levels (International Atomic Energy Agency (2007)). The IAEA report noted that having technical competencies related to nuclear technology is insufficient to ensure that the performance of an operating organization meets the necessary high standards for a sustainable nuclear industry. The report further outlined how such a code of ethics should be developed, implemented, and sustained.

The relevant ethical codes certainly merit approval, but only given valid implementation methods, and approval should not be limited to verbal declarations. In this context, let us consider NPP safety.

Emergency scenarios at NPPs most often involve four factors: uncontrollably high core power (breaking the change in reactivity); the loss of coolant flow through the core; the primary loss of coolant; and a pressure increase in the primary system. To prevent such scenarios and their associated negative effects, personnel require significant knowledge and the skills to conduct varied preventive maintenance (Ostreykovsky 1999). Otherwise, any obligations to ensure NPP safety are merely a declaration.

The above example demonstrates the impossibility of the ethics associated with nuclear facility operation to be limited solely to general ethical principles. However, the relevance of such principles cannot be ignored. Any employee of a NPP must perform various operations, and employees not motivated by ethical principles generally cease to be properly attentive and careful. Thus, two undesirable trends affect professional development in the nuclear power industry: first, assigning a declarative character to ethical codes, and, second, obliviousness to an ethical base. Ethics is an effective way to organize the activities of nuclear industry employees only when it is not exogenous but endogenous relative to their activities.

Another problematic aspect of the ethics of nuclear technology should be noted. The ultimate goal of ethics in this area, as in any other field, is to achieve the desired public benefit; therefore, it is necessary to reconcile the interests of different groups.

For a long time in the Soviet Union, up until the Chernobyl disaster, only professionals were engaged in nuclear engineering. Thus, confusion arose when it became clear that ordinary people, who do not speak the language of specialists, had their own opinions about this industry. It then became necessary to tailor nuclear engineering concepts for different social groups. It also emerged that even professionals, including physicists, technologists, chemists, and psychologists, frequently misunderstood one another. This phenomenon tends to be ignored, but its existence can cause severe conflicts.

We consider that the main moral lesson of nuclear technology development, in the modern context, is the fact that it increases the relevance of ethics, followed by its effectiveness being ensured by highly qualified research.

Nuclear Technology Basic Principles

An ethical analysis, both in general and in the nuclear field, should be pluralistic, coherently accepting different priorities, intentions, values, and norms, and simultaneously relying on a consensus regarding basic principles and rules (UNESCO Bangkok (2012)). The ethics of responsibility is the most suitable approach for the ethics of technology in general and nuclear technology in particular, because it integrates the abovementioned items and provides a holistic framework for analysis (Schuurman 2010).

Theoretical works also provide proposals for specific principles. Robertson proposed the following principles for the ethics of nuclear energy: no absolutes, no acceptable risk, no free lunch, alternatives and consequences, risk optimization, good intentions alone are insufficient, facts matter, and quantification where possible (Robertson 2003).

The most appropriate set of basic principles from the perspective of contemporary authors is that proposed by the IAEA. These principles may be divided into three categories: beneficial, responsible, and sustainable. That is, any use of nuclear technologies should be beneficial, responsible, and sustainable, with due regard to the protection of people and the environment, non-proliferation, and security (International Atomic Energy Agency (2008b). Nuclear Energy Series No. NE-BP). The proposed eight basic principles, on which nuclear technology should be based to fulfill its potential, help to sustainably meet growing global energy needs. These basic principles are intended to provide a holistic approach to the use of nuclear technology. Furthermore, they are to be equally applicable to all the elements of nuclear energy systems, including human and technical resources, management, and economic aspects, with due regard to the protection of people and the environment, security, and non-proliferation. We consider these basic principles below.

The beneficial use category includes two basic principles, namely benefits and transparency. Thus, nuclear energy should provide benefits that outweigh the associated costs and risks, and be based on the open and transparent communication of all relevant information.

The sustainable use category also includes two basic principles: resource efficiency and continual improvement, where nuclear energy should use resources efficiently and pursue advances in technology and engineering to continually improve safety, security, economics, proliferation resistance, and environmental protection.

The responsible use category includes four basic principles: the protection of people and the environment, security, non-proliferation, and long-term commitment. That is, the use of nuclear energy should be such that people and the environment are protected in compliance with internationally recognized standards. The risk of the malicious use of nuclear and other radioactive materials must also be considered, as should the proliferation of nuclear weapons based on a long-term commitment.

The IAEA is continuously developing the above concept, having proposed main considerations and specific goals to be achieved at different implementation stages, all consistent with the basic principles. A number of objectives have been identified for the following areas: general nuclear objectives, nuclear power objectives, nuclear fuel cycle objectives (including radioactive waste management), and decommissioning objectives (International Atomic Energy Agency (2011c). Nuclear Energy Series No. NW-O) (International Atomic Energy Agency (2011b). Nuclear Energy Series No. NF-O) (International Atomic Energy Agency (2011a). Nuclear Energy Series No. NG-O) (International Atomic Energy Agency (2009). Nuclear Energy Series No. NP-O).

Ethics should also provide for the problematization of challenging areas to identify possible trade-offs that balance the risks and benefits associated with conflicting factors. Thus, ethics may be considered a guide for practical decision-making.

One example where the implementation of ethical analysis seems useful is the assessment of the potential of nuclear technologies to meet the sustainability requirements developed within the framework of the IAEA's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO). A key objective of the INPRO is to help ensure that nuclear technology can contribute to sustainably fulfilling energy needs in the 21st century. The INPRO methodology for nuclear technology assessment includes 14 basic principles, 52 user requirements, and 125 criteria with indicators and acceptance limits—all of which must be met to ensure the sustainability of nuclear technology (INPRO web-page).

Consideration through ethical paradigms may also be useful for the further development and modification of such methodologies, because such an analysis could answer a number of questions including how to structure and manage this volume of information, and how to organize and perform assessments. Such consideration can provide information on the effectiveness of a certain nuclear technology relative to alternatives, identify system vulnerabilities, and assess the effectiveness of measures to reduce the risks associated with those vulnerabilities.

On the Way Toward Developing the Ethics of Nuclear Technology

This section summarizes the major findings of the authors (Kanke 2003, 2009, 2010, 2013). It also formulates a potential methodological course to overcome stagnation and provides for the further development of nuclear technology ethics via the axiological multidisciplinary problematization of the main concepts in nuclear engineering using basic ethical paradigms: analytical, hermeneutical, and poststructuralist.

Factors Hindering the Development of the Ethics of Nuclear Technology

Ethics is a Multidisciplinary Endeavor that Determines the Most Effective Ways to Optimize Values

Values are concepts, namely, principles, laws, and variables of axiological or pragmatic sciences. Rather than being defined by nature, values are invented by humans and thus express their preferences. The natural sciences use descriptions rather than values. In contrast with values, descriptions do not express preferences. The difference between descriptions and values can be demonstrated by the example of the principles of physics and the technical sciences. The principle of least action is independent of people's preferences. Despite having discovered this principle, people did not design it in accordance with their intentions, preferences, and values. On the contrary, the basic safety principles for NPPs are invented by people, and thus people, rather than nature, exercise their preference for safety. This example shows the critical distinction between the technical sciences and physics. Unlike physics, the technical sciences are axiological rather than descriptive.

The subject of meta-science is science itself (e.g., principles, laws, and concepts), but not its objects. The subject of physics comprises such objects as elementary particles—the actors of four types of fundamental interactions. When physics itself becomes the subject of study, this results in the appearance of meta-scientific physics (we use this term to avoid misunderstanding related to the term 'metaphysics', which is widely used in philosophy in different contexts). Correspondingly, meta-technical science is focused on technical science. Thus, it is important to distinguish between basic science (called sub-science), and meta-science.

The need for multidisciplinarity in relation to ethics is constant. The effective optimization of values, if achieved in one discipline, does not guarantee its presence in other disciplines. A favorable optimization in one science may hinder its achievement in other sciences. Thus, advances in nuclear engineering may be incompatible with advances in ecology, politology, or economics. Ethics is focused on general (holistic) optimization, and the search for a compromise between conflicting values. The British utilitarians of the 19th century expressed this as achieving maximum happiness for the maximum number of people.

Unfortunately, modern philosophy is characterized by the fact that *the main obstacle to the development of professional ethics is the lack of productive interaction between the technical and human sciences.* For example, philosophers are condescending towards science, accusing it of methodological rigorism. Such condescension is typical of poststructuralists (postmodernists), hermeneuts, and even a certain portion of analytical philosophers. It is unacceptable because science by definition is no more or less than the most advanced knowledge, and thus needs development not demonization. This condescension substantially slows the development of ethics by making it an abstract theory without links to other sciences. Consequently, it becomes difficult for representatives of different sciences, including nuclear engineering, to apply the achievements of philosophical ethics. For the most part, scientists consider philosophical ethics to lack real life applications.

On the contrary, representatives of sub-sciences, including physics and nuclear engineering, show little (if any) desire to apply meta-science to solve real problems. They tend to show an uncritical attitude to the philosophy of science, and make unflattering remarks towards philosophers. However, this attitude is clearly wrong. The proportion between sub- and meta-science is excessively hypertrophied. The development of meta-science is a problem for scientists of any specialization. Meta-technical science should be developed by technical scientists rather than philosophers, as the latter inevitably bring their own interests to the task. Science cannot be reduced to a sub-science. A sub-science is a first-order language that, whenever necessary, should be supplemented by a second-order meta-scientific language, such as the language of ethics. This reality dramatically hinders the development of professional ethics, including the ethics of nuclear technology, which is a meta-scientific discipline. Interdisciplinary links between philosophy and other sciences largely neutralize the adverse effects of this reality.

Philosophical Pluralism Should be Considered in the Development of Professional Ethics

Ethics is a philosophical discipline. The establishment of ethics as a field of study is usually ascribed to Aristotle (384–322 BCE), the author of three great works on ethics. From the time of Aristotle to the present, ethics has developed as a branch of philosophy. Obviously, during 24 centuries of development, a large arsenal of ideas related to ethics has been accumulated. In one form or another, such ideas should be considered in all forms of professional ethics, including the ethics of nuclear technology. The failure to consider such an arsenal will result in ethics based on excessively narrow perspectives.

Modern knowledge is pluralistic; no single individual can possess the truth. In the absence of pluralism, either pluralism is condemned or unrestrained eclecticism flourishes. In this case, attention is drawn to philosophical pluralism, which is most pronounced in the notorious opposition of analytical, hermeneutical, and poststructuralist ethics. These forms of ethics did not emerge by chance. If a representative of an axiological science ignores them, that individual is doomed to ‘township’ ethics.

Analytical ethics, or pragmatic ethics, enjoys wide acceptance in the United States. This form of ethics is understood as pragmatism, created by Ch. Pierce, James, and Dewey as a substitute for British utilitarianism. Pragmatists insist on the most effective resolution of problems. They gravitate towards decision-making theory, and thus provide this theory with a formal character. Decision-making theory comprises ways to improve the criteria for value assessment, which is the key point in ethics.

Hermeneutic ethics was developed in the former Federal Republic of Germany by Habermas and Apel, related to the ethics of responsibility. Hermeneutic ethics is based on the idea that people's mutual responsibility is formed through developed discourse rather than enforced by strong-willed decisions. However, to avoid a struggle between ill-founded opinions, this discourse needs not only to be organized, but also conducted according to certain rules. The above authors consider that discourse both influences and drives science.

Poststructuralist (postmodernist) ethics is a 'carte-de-visite' of modern French philosophy headed by Derrida and Lyotard. This form of ethics focuses on the originality of individuals, which excludes agreement between people. Individuals play language games to achieve personal advantage, and ignore both hermeneutical consent and decision-making theory.

It is reasonable to synthesize the achievements of the three abovementioned forms of ethics, as well as some of their variants. Therefore, there appears to be hope for competition with potential pragmatic, hermeneutical, and poststructuralist opponents. These forms of ethics all favor a single variant of philosophical ethics without properly assessing the strengths of alternatives.

Technical experts, scientists, and engineers should definitely take into account the achievements of the spectrum of philosophical ethics, because all philosophical terms are translated into the language of the corresponding meta-technical science. In other words, taking these achievements into account involves a kind of modeling, called techno-philosophical modeling. The crucial feature of any type of modeling is that the science-contributor concepts are used to indicate science-acceptor concepts. In the semiotics of Ch. Pierce, such signs are called 'symbols'. In the present case, the science-acceptor is nuclear engineering, while philosophical ethics acts as the science-contributor. This translation is obligatory and should be thoroughgoing. Thus, every philosophical term should be translated into the language of nuclear engineering to avoid scholasticism.

The Main Way to Develop the Ethics of Nuclear Technology is Via Axiological Multidisciplinary Problematization

A poor awareness of ethics often leads scientists to misconceive the ways ethicization can be implemented within a specific science, including nuclear engineering. Hence, they completely ignore ethics, uncritically apply the concepts of philosophical ethics, or invent codes of ethics that do not sufficiently reflect the specifics of their field of science. The main pathway of the ethicization of nuclear engineering may be as described below.

Five Development Stages of the Ethical Content of Nuclear Engineering

First, it is necessary to clearly separate technical and physical concepts. For all the relevance of physics to nuclear engineering, it is no more than a science-contributor. Attempts to reduce nuclear engineering to physics are widespread, but such efforts reduce the role of ethics. Physicists are by no means neutral in relation to ethics. However, physicists become concerned with ethics not because of physics per se, but rather its interdisciplinary links with the axiological sciences. For example, the

Pugwash Movement was established by a group of physicists, headed by Albert Einstein.

Second, it is essential to express the axiological structure of nuclear engineering by taking into account the subordination of its principles. In typical deduction, a concept with a higher axiological weight produces the underlying concept. Therefore, for example, if the principle of safety is made fundamental, this will determine the content of the principle of reliability. Meanwhile, if reliability is prioritized instead, as was the case before the Chernobyl disaster, this will determine the main features of the principle of safety. The content of axiological principles determines the status of axiological laws, that is, links of values.

Third, it is important to carefully problematize values in use, paying particular attention to their origin, modification, and critical update through more advanced concepts, methodologies, and frameworks. Doing so represents the upgrade of nuclear engineering from a sub-science to meta-science. Upon the successful implementation of the third stage, a real and professional code of ethics of nuclear technology will emerge. Thus, ethics grows together with nuclear engineering rather than being exogenous.

Fourth, it is essential that ethically-oriented techno-philosophical modeling occurs. This disrupts the borders of purely professional ethics and lends them an interdisciplinary character. Philosophical ethics, despite its shortcomings, offers tremendous prospects in this regard. We should not forget that philosophical ethics absorbs ideas from many sciences, and these ideas may be felt in techno-philosophical modeling.

Fifth, it is vital to adopt ethically oriented multidisciplinary modeling. This connects the ethics of nuclear technology with other professional ethics. In this case, the optimization of values acquires a global character. Thus, the professional boundaries of the ethics of nuclear technology can finally be surmounted. The completion of such multidisciplinary modeling means that the ethics of nuclear technology has reached saturation. However, the development of ethical thought does not freeze at this point. Rather the ethics of nuclear technology reaches a stage typical for the ethics of any science: as science advances the problems are never overcome, instead they are refined and sharpened.

The five development stages of the ethical content of nuclear engineering already exist but in an undeveloped and haphazard form. Significant progress in the development of the ethics of nuclear engineering will not come automatically—it relies instead upon the focused work of enthusiasts. Thus, extensive and complex work is required, and this will not occur without a multidisciplinary spectrum of competences.

Summary

The technical sciences belong to a class of pragmatic disciplines that are guided by the pragmatic method, and their axiological multidisciplinary problematization inevitably results in the development of new fields of ethics. The technological developments of the second half of the 20th century were first accompanied by a general obliviousness to ethics, and then by its rehabilitation.

The development of ethics in relation to a specific technical field typically goes through several stages: (a) the use of traditional ethical maxims; (b) the development of an appropriate professional code; (c) and the detailed understanding of values based on refined theories. Modern technoethics is guided by the principles of responsibility. With respect to the various aspects of human technical undertakings, it is still critical that we develop ethics that are endogenous to these activities. The ethics of nuclear technology has followed the above path.

Initially, the development of nuclear technology was accompanied by hasty actions and only superficial consideration was given to their ethical implications. When people realized the need for an ethics of nuclear technology, they turned to well-known moral maxims from religion and philosophy. A significant step forward was the development of various codes of ethics for nuclear industry employees. People gradually realized the need to turn the ethics of nuclear technology into an endogenous concept related to the concepts of nuclear engineering. The main moral lesson in the development of nuclear technology is the finding that, within the present conditions, first, the relevance of ethics is increased, and second, its effectiveness is primarily ensured by highly qualified research.

Despite the efforts undertaken so far, some of which are reviewed in this article, the professional ethics of nuclear technology remains immature and it is essential that a comprehensive analysis of existing experience and best practices occur. The authors hope that a summary of the major reasons hindering the development of ethics of nuclear technology, as well as the potential methodological course for overcoming stagnation and providing further development, will stimulate professional discourse and finally lead to the emergence of alternative perspectives on this issue.

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