Ethical Issues in Nuclear Engineering

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CONTENT

1 What is Nuclear Technology?

Nuclear technology is special. Although nuclear energy is part of the nature, the amount of radioactivity created by the use of nuclear technology is enormous compared to the level of radioactivity in the nature. There is a potential for the release of these radioactive materials into the environmental through reactor accidents and during the disposal of nuclear waste. With radiation known as universal human carcinogen, there are clearly concerns over potential human health impacts. Some of the radioactive materials are very long lived and, if not properly taken care of, their presence in the environment could adversely affect the public health for many generations. Nuclear technology also carries dual use potential. It can be used for both peaceful civilian and military purposes. The fact that the technology was first manifested in the form of the most potent bomb left a strong negative imprint in the collective memory of the humanity. Although civilian nuclear technology is not directly related to weapons work, the expertise, equipment, facilities, and computer models can be used to help develop clandestine nuclear weapons facilities. The public's attitude toward nuclear technology has been mixed; affected by the fear of accidents and concern over nuclear waste management. Although the fear or anxiety the public experiences may not be scientifically grounded, they are real and need to be addressed by the people who manages the technology.

With the world's continuing concern over global warming and oil reserve deplition, nuclear energy is receiving renewed interest. Presently, about 440 nuclear power plants are in operation in 34 countries around the world providing about 16% of world electricity[1]. Nuclear power reduces the production of about 8% of the present level of CO_2 emissions in the energy sector.

1.1 *Importance of an Engineer's Role in the Use of Nuclear Technology*

Due to special character of nuclear technology, nuclear engineers who manage the technology must be specially trained for their jobs.

As Weinberg mentioned, nuclear energy was a Faustian bargain[2] in which we accept an inexhaustible and non-directly polluting energy source at the cost of potential for destructive power and long-term waste impact requiring a high degree of care and surveillance. Weinberg asserted[3] that *we are immoral if we do not exert every humanly possible effort to uncover, assess, and remedy whatever deficiencies we can find in nuclear energy.*

[1] The TOPS Task Force of the NERAC, Technological Opportunities To Increase the Proliferation Resistance of Global Civilian Nuclear Power Systems (TOPS), p.5, January 2001.
[2] A. M. Weinberg, 1972, Rutherford Centennial Lecture at the annual meeting of the American Association for the Advancement of Science, December 1972.
[3] Ibid.

The people who man the enterprise must have qualities that match the demands placed on them by the special nature of nuclear energy, thus requiring professionalism and dedication of those who are entrusted with the nuclear enterprise[4]. You start developing such a culture as soon as you become a student in one of the nuclear engineering schools or departments in the nation (read Chapter 2).

The responsibilities of a nuclear engineer as a holder and a steward of the technology are addressed in this discussion using four major themes:
(1) Developing and maintaining nuclear safety culture;
(2) Developing and maintaining nonproliferation culture;
(3) Making responsible judgments and decisions regarding nuclear/radiation risk management; and,
(4) Appropriately addressing public concerns over the use of nuclear technology.

1.2 Four Themes in Addressing Ethical Responsibilities of Nuclear Engineer

1.2.1 Nuclear Safety Culture

Case Example: Chernobyl

The Chernobyl disaster happened in 1986 at the Chernobyl nuclear power plant in the Ukraine was the result of a flawed reactor design combined with several serious mistakes made by the plant operators[5]. The accident began with a test to investigate the ability of the turbine generator during an event of a loss of external electricity power. To do this experiment, the operator reduced the power level of the reactor. But the operator did not know that this reactor (RBMK: Russian reaktor bolshoi moshchnosty kanalny which means "reactor (of) large power (with) channels") at very low power level is in very unstable condition. After the rapid power level drop, the operator pulled out too many control rods to raise the power output (only 6-8 control rods were used at that moment while minimum 30 rods were required in a standard operating order). After the operator shut down the steam supply to the turbine, the reactor responded with power rising. The automatic control rods failed to lower the power because of their slow speed. The further full insertion of emergency control rods even boosted the power rising in the first six seconds (bad emergency control rods design) instead of reducing the power. A nuclear burst started after further fuel temperature rising 40 seconds after the beginning of the experiment. The following explosion caused by graphite further destroyed the reactor. Without a reactor shielding, a large amount of radioactive materials were released during and after the explosions.

It is considered to be the worst accident in the history of nuclear power. According to the 2005 report prepared by the Chernobyl Forum, led by the International Atomic Energy

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[4] See Weinberg (note 2).
[5] World Nuclear Association, "Information and Issue Briefs: Chernobyl Accident", March 2006, <http://www.world-nuclear.org/info/chernobyl/inf07.htm>

Agency (IAEA) and World Health Organization (WHO), the accident resulted in 56 direct deaths and as many as 9000 people among approximately 6.6 million citizens that are most highly exposed are estimated to die from some form of cancer[6].

The causes of the accident are summarized as follows[7]:

- *Design fault in the RBMK reactor*: the reactor may lose control under certain condition
- *Lack of a "Safety Culture":* this results in an inability to remedy design weaknesses despite the fact that it was known before the accident.
- *Violation of procedures:* a test of the reactor was run under violation of the safety procedures; only 6-8 control rods were used (minimum 30 rods were required in a standard operating mode) and the reactor's emergency cooling system was disabled.
- *Communications breakdown*: an insufficient communication between the safety officers and the operators who run the experiment that night.

Chernobyl accident has happened and is now part of our history that cannot be changed. However, a review of this accident can help us learn a very important lesson. Herein, we only review this accident from the aspect of ethics: this accident is caused by flaw design of a reactor and fault operation violating the safety procedure. The operators did not know about the unstable reactor condition at very low power level and they led the reactor into such mode of operation. ***The operators were engaged with the services that they were not qualified by training or experience to perform***. During the experiment, the control rods were pulled out much more than what is permitted by the standard order, ***the operators violated the prescribed procedures***. Had there been no violations, the Chernobyl accident would not have happened. The designers of the reactor probably were aware of the design flaws but did not remedy this problem nor warned the operator of the special modes of reactor operation. After the accident, the management did not disclose the details of the event to the workers and the public which could have reduced the public health impact to a large degree.

Engineer's Responsibility on Safety Culture

Nuclear and radiological safety are the prime concerns in the use of nuclear technology. Safety is compliance driven and is based mainly on rules and regulations[8]. If individuals do not follow the rules and regulations, safety is unattainable. The immediate causes of major accidents are often identified as human errors or technical failure. But probing the accident events usually reveals that more fundamental issue is directly linked to the *safety culture*.

The safety culture in an organization is the product of the individual and group values, attitudes, competencies, and patterns of behavior that determine the commitment to, and

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[6] IAEA, *"In Focus: Chernobyl"*, Retrieved on 2006-03-29.

[7] <http://www.chernobyl.co.uk/>

[8] International Nuclear Safety Advisory Group, Key Practical Issues in Strengthening Safety Culture, INSAG-15, IAEA, 2002.

the style and proficiency of, an organization's health and safety programs. Organizations with a positive safety culture are characterized by communications founded on mutual trust, by shared perceptions of the importance of safety, and by confidence in the efficacy of preventive measures[9]. In organizations with a strong safety culture, a large proportion of the workforce, often working in teams, will be committed to and actively involved in a continuous process of safety enhancement as part of a learning organization[10]. Although nuclear safety is collective responsibility and culture is the sum total of a group's learning, at the fundamental level an individual's attitude and effort will make a difference. All personnel must understand the importance of adherence to nuclear safety standards. People and their professional capabilities, values, and experiences are regarded as the nuclear organization's most valuable asset[11]. For example, in a nuclear power plant, operators need to be vested with the authority and understand the expectation, when faced with unexpected or uncertain conditions, to place the plant in a safe condition. The plant management must support and reinforce conservative decisions. Engineers and other employees must be encouraged to review their actions using approaches as <u>STAR</u> (Stop, Think, Act, and Review) and seek help where there is any doubt about safety, even if the actions may lead to delays or some loss of production[12]. Engineers must be prepared to be responsible to the best of their knowledge in the use of engineering judgments and decision making with respect to safe operation of nuclear systems.

1.2.2 Nuclear Nonproliferation Culture

<u>Case Example: A. Q. Kahn</u>

Pakistan started its nuclear weapon program in 1972 shortly after it lost East Pakistan in the 1971 war with the neighbor India. India's nuclear test program in 1974 further influenced the Pakistan's nuclear weapon program to continue to develop. The join of Dr. Abdul Qadeer Khan in 1975 accelerated the progress of Pakistan's enrichment technology development. Dr. Khan is a metallurgical engineer who is regarded as the founder of Pakistan's nuclear weapons program. Dr. Khan was born in India and migrated into Pakistan in 1952. He went to Europe for education after his college training in Pakistan. In 1972, Dr. Khan obtained his PhD from the Catholic University of Leuven in Belgium. He stared to work in the Physical Dynamics Research Laboratory (called FDO) in Netherlands that same year. FDO was a subcontractor for URENCO, which was the uranium enrichment facility in the Netherlands to assure enriched uranium supply to European nuclear reactors. During the time he worked there, he gradually had privileged access to the most secret areas of the URENCO facility and to documents on the gas centrifuge technology. Dr. Khan suddenly left Netherlands in January 1976 and was put in charge of Pakistan's nuclear weapons program. It was revealed in 2005 that the Netherlands knew of Dr. Khan stealing nuclear secrets. Pakistan obtained rapid development on enrichment capability with the help of Dr. Khan. The nuclear test in 1998 claimed nuclear weapon acquisition in Pakistan.

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[9] The Institution of Engineering and Technology, Health and Safety Briefing, No 07, December 2006.
[10] INSAG-15.
[11] Institute of Nuclear Power Operations, Principles for a Strong Nuclear Safety Culture, November 2004
[12] INSAG-15.

Dr. Khan not only stole the enrichment technology to Pakistan government but also to other countries like North Korea, Iran and Libya. It was believed that some scientists close to Dr. Khan had contacted with Taliban. In 2004, Pakistan government reported that Dr. Khan transferred the technology to Iran between 1989 and 1991 in exchange of millions of dollars, and also to North Korea and Libya between 1991 and 1997. It is believed that Dr. Khan had put the sensitive technology into black market for money and eagerness that help Muslim countries to obtain and expand the nuclear technology. After two years investigation by Pakistan government, it was confirmed in 2005 that Dr. Khan had supplied enrichment facility parts to North Korea and a bomb design to Libya. Enrichment technology is a very key technology to build nuclear weapon. Dr. Khan's proliferation activities increase the risk of spreading nuclear weapon to the world.

Dr Khan's activities in FDO obviously violated all the applicable laws. He did not act in a professional and ethical manner in his own conduct nor acted as a faithful agent of the technology he was in charge of. His proliferation activities increased the risk of spreading nuclear weapon and severely undermined the safety, health, and welfare of the public in the world.

Engineer's Responsibility on Nonproliferation Culture

Use of nuclear energy has been controversial from the very beginning since it is the technology that has potential for both peaceful and destructive purposes. Most countries owning nuclear technology have drawn clear physical boundaries between military and civilian nuclear programs. Developing civilian nuclear capability does not bear direct relationship with nuclear weapon development. Although civilian nuclear technology is not directly related to weapons work, the expertise, equipment, and facilities can be used to develop facilities for weapon development. Many of the people who deal with material, facilities, equipment, and computer models related to making nuclear weapons[13] learn the skills necessary and useful for nuclear weapon making by engaging in civilian nuclear power programs.

Acquiring nuclear weapon-usable material can be pursued in three different routes[14]: (a) Enrichment of uranium-235 to weapons grade concentrations through isotope separation; (b) Chemical reprocessing of spent fuel from reactors to extract plutonium-239, uranium-233, or other weapon-usable fissile materials; (c) Diversion, theft, seizure, purchase, or receipt of fissile nuclear materials. A civilian nuclear power program can potentially be linked to all of these routes if uranium enrichment or spent fuel reprocessing is involved. It has been shown that reactor-grade plutonium from civilian nuclear reactors is a potentially explosive material and that the difficulties of developing an effective design of the most straightforward types (e.g., Fat Man-type) are not appreciably greater with

[13] Hassberger, J., T. Isaacs, and R. N. Schock, "A Strategic Framework for Proliferation Resistance: A Systematic Approach for the Identification and Evaluation of Technology Opportunities to Enhance the Proliferation Resistance of Civilian Nuclear Energy Systems," UCRL-JC-142356, Lawrence Livermore National Laboratory, 2001.
[14] H. Feiveson, "Proliferation Resistant Nuclear Fuel Cycles," Annual Review of Energy, 3: 357-394, 1978.

reactor-grade plutonium than those that have to be met for the use of weapons-grade plutonium[15]. Thus it is possible to build entirely credible national weapons capability with use of only reactor-grade material[16].

Proliferation takes place when the fissile materials from the civilian nuclear power program are diverted and know-how from the civilian nuclear programs is used for military purposes. Training and education of people to support nuclear power program is linked to nuclear proliferation as many of the skills and capabilities of nuclear scientists and engineers are common between civilian and military program.

Examination of nuclear proliferation history indicates that except for the early nuclear weapons states such as the U.S., Soviet Union, U.K. and China where weapons programs predated civil applications, most of the states with nuclear ambition have used civilian nuclear power programs as cover for any on-going weapons work. The list of these countries includes France, Brazil, South Africa, Argentina, South Korea, North Korea, Taiwan, Pakistan, India, and Israel[17].

It has also been noted that technological barriers of nuclear reactor systems cannot prevent a determined state from a proliferation attempt. Technology has promises and limitations in preventing proliferation. The people engaged with the use of nuclear technology must practice highest levels of moral values in their professional activities and to refrain from any clandestine engagement for illicit weapon development. If the holders of the knowledge practice their own code of ethics, the barrier that technical expertise plays will be effective[18]. If the situation is the opposite, the technical barriers will no longer be limiting, defeating the purpose of many of the technical and technological development for proliferation resistance.

Within the nuclear community, each engineer must strive to enhance and fortify the culture and ethics of nonproliferation through active communications among the professionals. The world's nuclear community must demonstrate continued commitment to clear severance between the civilian and military applications. An integrated approach to address human, political, institutional, and technical factors must be utilized to avert the spread of nuclear weapons[19].

1.2.3 Responsible Risk Assessment and Management

<u>Case Example: Radiation Spill at Hanford</u>

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[15] J. C. Mark, "Explosive Properties of Reactor-Grade Plutonium," Science and Global Security, 4, 111-128, 1993.
[16] See Feiveson (Note 14).
[17] Bunn, M., "Civilian Nuclear Energy and Nuclear Weapons Programs: The Record," International Topical Workshop on Proliferation-Resistance in Innovative Reactors and Fuel Cycle, International Atomic Energy Agency (IAEA), Como, Italy, July 2-6, 2001.
[18] See Hassberger, et al. (note 13).
[19] See TOPS (note 1).

As a part of the Manhattan program, Hanford nuclear site was chosen to construct industrial-size plants to produce plutonium in December 1942. The Hanford site is 560 square miles and is located in south central Washington State by the Columbia River flowing through it for 51 miles. 53 million gallons of the high-level waste from the process of plutonium production were stored in the 177 single and double-shelled tanks at the site. The integrity of the tanks was believed to last long enough until a waste disposal technology could be developed. But in 1953, the U.S. Geological Survey observed that the tanks are potential hazard and concluded that their structural life is not entirely known. The Atomic Energy Commission (AEC) ignored this warning and continued to use the tanks. In 1957, the AEC disregarded the suggestion from a National Academy of Sciences (NAS) panel that high-level waste should be buried in bed salt formations. On 29 January 1959 in a congressional hearing, the manager of Hanford chemical plants predicted that the tanks would work for “decades” and possibly as long as 500 years. Even though they had observed suspicious undergoing of the fluid levels in some tanks, they still believed none of the tanks had leaked. But a Government Accounting Office (GAO) report on 29 May 1968 showed that the first major leak of 35,000 gallons, happened in August 1958, which was six months before the prediction of 500 years lifetime for the tanks and only around 15 years after the tanks were first used. It was estimated latterly that the service life of remaining tanks was 10 to 20 years. Eventually, about 1 million gallons of highly radioactive waste has been leaked into the ground from 67 of the single shell tanks causing major concerns over the contamination of the Columbia River.

A large scale leakage of nuclear waste at Hanford could in part be attributed to an irresponsible/unwarranted remark of a nuclear engineer at a position of significant responsibility. How could the engineer make such a confident predictive remark given the magnitude of uncertainty associated is a major question. The remark was made while the leakage was already happening six month prior to the hearing. Why did they believe that there was no leakage when they observed the fluid levels had gone down suspiciously? Given the uncertainty, the engineer was not qualified to make such a confident optimistic prediction of the service life of the tanks.

An Engineer’s Responsibility on Responsible Risk Assessment/Management

Scientists and engineers may be in a powerful position to influence decisions because many hazardous substances or activities are associated with hidden and delayed effects that can be uncovered and assessed only with highly skilled methods. It is clear that scientific and technical experts provide their knowledge, expertise, experience, and judgment to evaluate and predict the risk. However, scientific analysis may not always be neutral and objective as decision-making instruments, even if it satisfies all the tests of scientific peer review. Good scientific analysis is neutral in the sense that it does not seek to support or refute the claims of any party in a dispute. It is objective in the sense that any scientist who follows the rules of observation in some special field of study can in principle obtain the same results. But science is not necessarily neutral and objective in its ways of framing problems.

It becomes obvious that scientific data about risks are not only interdisciplinary and complicated, but they are characterized by certain intrinsic limitations. Limitations of models and methods in risk assessment comprise different issues including the impact of expert disagreements, different attitude to a probabilistic approach, and uncertainties in risk analysis. In this regard, three general sources of uncertainty can be recognized: model uncertainty, input data uncertainty, and general quality uncertainties[20]. Model uncertainty, a measure of the degree to which a model fails to represent reality, reflects the weaknesses, deficiencies, simplifications, and inadequacies intrinsic to any model. Data uncertainty means uncertainties in input parameters to models that result from incomplete and often unavailable data, so it leads to fill gaps through estimation, inference, or expert opinion. General quality uncertainties involve two aspects of quality assurance: completeness and comprehensiveness.

For all of these uncertainties, another factor that affects the execution of risk assessment is the subjective nature of estimating uncertainty (called subjective uncertainty: *uncertainty in estimating uncertainty*). Subjective uncertainties are introduced in the process of eliciting expert judgments as there is a tendency among experts to be overconfident[21].

The fact that human society and its evolution over the centuries to come cannot be predicted is a principal source of social uncertainty related to the risk assessment of nuclear waste disposal. Other sources of social uncertainty associated with risk and performance assessment of a high-level nuclear waste repository also include[22]:
(1) *Uncertainties of consequences*: Estimates of the overall risk related to high-level NWD must necessarily be based on an incomplete list of possible consequence. These estimates may be viewed as decision making in the face of unknown possibilities;
(2) *Uncertainties of values*: Decisions and choices made both individually and socially are guided by social values. Hence, outcomes or consequences of those choices are measured in term of values, such as human well-being, ecological diversity, or money. Because individuals, groups, and organization often weigh these values in different ways, many social decisions and choices become difficult and contentious. These difficulties are particularly true for the choices related to the high-level NWD because extraordinary uncertainties are associated with the values to be applied;
(3) *Uncertainties of demarcation*: Different individuals (experts), groups and organizations view the focus, scope, and time frame of the high-level NWD in different ways, and it is not clear which opinion will dominate. Each context can provide a basis for decision-making, but uncertainties abound as to which provides the appropriate scope of analysis or set of decision norms.

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[20] Stricoff, R.S. 1996. Safety Risk Analysis and Process Safety Management. Principles and Practices. In: Rao V. Kolluru (ed. in chief), *Risk Assessment and Management Handbook. For Environmental, Health, and Safety Professionals*. New York: McGraw-Hill, Inc, pp. 8.3-8.53.
[21] Morgan M.G. and Henrion M. 1990. *Unceretainty: A Guide Dealing with Uncertainty in Quantitative Risk and Policy Analysis*, New York: Cambridge University Press; Cooke R.M. 1991. *Experts in Uncertainty: Opinion and Subjective Probability in Science*, Oxford University Press.
[22] Flynn, J., Chalmers, J., Easterling, D. 1995. *One Hundred Centuries of Solitude. Redirectering America's High-Level Nuclear Waste Policy*. Boulder: Westview Press.

There are also limitations to the applications of the results of analytical research to risk management decisions (e.g., problems of acceptability and "de minimis" risk) due to a range of uncertainty within which the decision makers have to operate. There is a limit in the space of possible responses to what scientific methods and procedures can be answered. Weinberg has noted this limitation as "trans-scientific", this regards questions that can be stated by the language of science but unanswerable by science[23]. The extrapolation of adverse biological effects to vanishing low concentrations of toxic substances, or the probability of extremely improbable events provide typical examples of trans-scientific questions.

A complete resolution of uncertainty represents the same kind of idealism and naivety as does the zero-risk philosophy. However, an engineer needs to be humble and transparent about what you don't know. In the use of engineering judgments and decision making with respect to risk management of radioactive materials, an engineer must be prepared for a worst case. Because we do not want to step over a cliff while learning from experience, it makes sense **to protect against unacceptable risks where feasible.**

1.2.4 Addressing Public Concerns in the Use of Nuclear Technology

Case Example: Three Mile Island

The Three Mile Island accident of 1979 was a severe accident with melt-down of a portion of the reactor core. When the governor of Pennsylvania issued a calm and measured advisory suggesting that pregnant women and preschool children living within five miles of the plant might want to evacuate and that all other people within ten miles ought to consider taking shelter in their homes, some 200,000 poeple were alarmed enough to take to the public highways. And they fled, on average, a remarkable 100 miles[24]. This is a wild discrepancy between the scale of an advisory and the scale of an actual evacuation. A deep and profound dread was driving the behaviors of the evacuees. At the same time, the accident has not been associated with any actual fatality. Nonetheless, the accident, with the massive information flow at the time of accident, caused shut down of nuclear plants worldwide, caused a huge increase in the cost of nuclear energy generation, and eroded public confidence in nuclear industry and regulatory institutions[25]. The accident did redefine the importance of human factors in engineering design, operation, management, and public communication of a risky technology. Although the resulting health effect from the accident was less than one fatal cancer among the total affected population, many people experienced a huge psychological stress thinking that their home, their body and lives were utterly tainted by the radioactive contamination. Although the accident did demonstrate the safety of

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[23] Weinberg, A.M., 1972. Science and Trans-Science. *Minerva*, 10: 209-222.

[24] Erikson, K., "Toxic Reckoning: Business Faces a New Kind of Fear," *Harvard Business Review*, January-February, 118-126, 1990.

[25] Kasperson R.E. and J. X. Kasperson, "Hidden Hazards," In: D. G. Mayo and R. D. Hollander (eds.) Acceptable Evudence: Science and Values in Risk Management, Oxford University Press, New York, NY, 1991.

commercial nuclear power plant in terms of the consequences, the damage done to the industry was incalculable.

Engineer's Responsibility on Public Risk Perception

A common explanation by the technical community of the behavior of the public regarding risk warning or the existing nuclear risk perception of the public is that the public is irrational, poorly informed, and negatively biased. Typically a nuclear engineer would believe that information and education will change the situation - the more people understand about nuclear power, the more they tend to favor it. In this vein, the nuclear industry waged massive national advertising campaigns for public education. However, these campaigns were not very successful. There have been mixed views on the effectiveness of education on affecting public risk perception on nuclear energy. Although there were a few exceptions, most of early experimental studies did not show a positive effect of education in changing public risk perception. The arguments that opposition toward nuclear energy stems from ignorance, and thus greater information will change attitudes, lacked solid empirical evidence.

At the same time, although the fear or anxiety the public experiences may not be scientifically grounded, they are real and need to be addressed by the people who manages the technology.

The potential of the nuclear technology for energy generation was first manifested in the form of a most potent bomb during a world war. In the early days of the environmental awakening era in the U.S., environmental activists played a critical role. Nuclear technology was considered a symbol of commitment to growth, consumption, and high technology which were the nexus of concern among the environmental activists in the 70s[26]. A network of environmental groups provided the leadership to anti-nuclear organizations at state and local levels. Concerns on the safety of reactor operation, disposal of nuclear waste, and possible diversion of nuclear material capable of use in weapons manufacture, sometimes in the form of horror stories, were the more visible counts in these opposition movements involving the public. Exploiting the wave of distrust in institutions which had been heightened by the Vietnam war and Watergate tragedies along with the timely occurrence of the Three Mile Island accident, the anti-nuclear movement was extremely successful with fear/dread appeals and affected many people through the central information processing mode.

Rothman and Lichter, in their investigation of risk perception in nuclear energy policy, have argued that nuclear energy is "a surrogate issue for more fundamental criticism of U.S. institutions"[27] The government's history of mismanaging nuclear waste also further damaged the perception of nuclear technology. This include the events such as the Lyons, Kansas high-level waste (HLW) repository debacle, leaking HLW tanks at the Hanford

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[26] Kasperson et al., 1980

[27] Rothman S. and S. R. Lichter, "Elite Ideology and Risk Perception in Nuclear Energy Policy," *American Political Science Review,* 81, 81, 1987.

reservation, near-critical mass development at Hanford 'cribs', and building constructions with uranium mill tailings in Colorado, etc[28]. Lack of trust through this history was further complicated by global, regional, and procedural concerns[29].

The nuclear industry has reached a critical turning point with the passage of site approval of the Yucca Mountain repository along with the renewed interest in nuclear energy in the country. Many of the current members of the public have never experienced the anti-nuclear movements or the nuclear risks personally. This is an opportune time for the nuclear industry to gain trust and credibility from the public. Gaining trust and credibility requires repetitive demonstrations of a transparent corporate behavior respecting the views of vulnerable parties and empathizing with the interests of the public[30]. They need to maintain consistent levels of successful operational performance.

Nuclear engineers must also understand that the majority of the public do not work under the same rules of rational thinking. There are two different frameworks of thinking, technical rationality and cultural rationality. While the engineering and scientific community lives in the world of technical rationality, the rest mostly are in the cultural way of thinking. Technical rationality is based on well-defined sets of principles and scientific norms, including hypothetic-deductive methods, a common language for measurement, quantification and comparison of risk events. The emphasis is made on objective (non-personal) data rather than subjective (experiential) information. The cultural rationality does not deny the role of technical reason; it tries to extend the latter. Cultural rationality trusts in political culture and democratic process rather than in scientific methods. Boundaries of analysis are broad and risks are personalized in cultural rationality while risks are depersonalized in technical rationality with narrow boundaries of analysis. Cultural rationality emphasizes the impacts of risk on the family and community and focus on particularity while technical rationality emphasize statistical variation and probability stressing consistency and universality. Unarticulated and unanticipated risks are relevant with cultural rationality while those impacts that cannot be articulated are irrelevant with technical rationality.

Powell and Leiss note a new phenomenon in risk communication calling it "the risk information vacuum"[31]. It is related with the gap that separates the scientific description of risks and the public understanding of those same risks (see above). In many cases this gap cannot be closed appreciably because the scientific and public apprehensions of a risk are framed by fundamentally different assumptions or values. One of the most serious manifestations of this gap is the emergence of a risk information vacuum. The risk information vacuum arises where, over a long period of time, scientists and experts

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28 Lipschutz, R. D., Radioactive Waste: Politics, Technology, and Risks, Ballinger Publishing Company, Cambridge, MA, 1980

29 Dunlap, R. E., M. E. Kraft, and E. A. Rosa, (Eds.), Public Reactions to Nuclear Waste, Duke University Press, Durham and London, 1993.

30 La Porte, T. R. and D. S. Metlay, "Hazards and Institutional Trustworthiness: Facing a Deficit of Trust," *Public Administration Review*, 56, 4, 341-347, 1996.

31 Powell D. and Leiss W. 1997. *Mad Cows and Mother's Milk. The Perils of Poor Risk Communication..* Montreal & Kingston: McGill-Queen's University Press

involved in research and assessments for high-profile risks make no special effort to communicate the results obtained regularly and effectively to the public.

Powell and Leiss state that society as well nature abhors a vacuum, so it is filled from other sources. Events reported in the mass media, become often the important basis of the public framing of these risks. Many of these events are alarming, especially those related to high technologies. Risk information vacuum can also be filled by different social groups or individuals aiming their own interests, providing their own information and perspectives. Sometimes safety concerns, suspicions, and fears of individuals based mainly on intuition and enhanced by the influence of different reasons (the lack of scientific data or their complexity, uncertainties in the risk estimates, deficit of trust or credibility) grow and spread to fill eventually the information vacuum. It means that a risk information vacuum can be regarded as a primary factor of the social amplification of risk. In the environment of a risk information vacuum, people's apprehensiveness, concerns, suspicions and fears, having latent character, may be developed and amplified to the level, where credible and adequate information is provided too late, so it makes no significant impact on the formation of the public opinion.

To improve risk communications, engineers and scientists must be actively engaged with the public. The technical and scientific community must understand the differences in the rationalities taken by the experts and the public. Framing of information with issue-relevance, perceived credibility of the presenter, and the method of information exchange will all be important in determining the effectiveness of the information exchange. These echoes with the following observation[32]: "Given an atmosphere of trust in which both experts and lay persons recognize that each group may have something to contribute to the discussion, exchange of information and deepening of perspectives may well be possible." An atmosphere of trust can be generated based on a belief that those with whom you interact will take your interest into account and a sense of confidence that the party trusted is able to empathize with your interests and is competent to act on that knowledge[33].

1.3 Concluding Remarks

More recent surveys of public attitude toward nuclear power show the turnaround trend for nuclear energy. The 2003 NEI study[34] showed that 7 out of 10 Americans believe nuclear energy should play a role in our energy future. And 57 percent would find it acceptable to add a new reactor next to the nearest existing nuclear power plant if a new source of electricity supply were needed. Support for new nuclear plants jumped 18

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[32] Slovic, P., B. Fischhoff, and S. Lichtenstein, "Informing People about Risk," in Product Labeling and Health Risks, L. A. Morris, M. B. Mazis, and I. Barofsky (Eds.), Banbury Report 6, Cold Spring Harbor Laboratory, 1980.

[33] La Porte, T. R. and D. S. Metlay, "Hazards and Institutional Trustworthiness: Facing a Deficit of Trust," *Public Administration Review*, 56, 4, 341-347, 1996.

[34] "Public Support for Building Nuclear Power Plants Increases Following August Electricity Blackouts," Perspective on Public Opinion, NEI, November 2003.

percentage points to 58 percent in the Northeast and 11 percentage points in the Midwest, where 66 percent said it would be acceptable to build a new reactor at the site of the nearest nuclear plant.

Recent performance of the nuclear power plant fleet in the U.S. tops near-record level 90% capacity factor. The operating/production cost of nuclear energy has been going down. Many of the U.S. utilities are vying for life-time extension through re-licensing and purchasing old units. So far the US Nuclear Regulatory Commission (NRC) has renewed the licenses for 23 reactors nationwide. There is a consortium of nuclear vendors and utilities under the support of U.S. Department of Energy preparing for the construction of a new nuclear power plant by 2010[35]. New reactor designs, including the development of new generation reactors[36], have actively been researched. Within the nuclear industry, these developments are considered a presage of nuclear renaissance in the U.S. Expectation among the U.S. nuclear industry is that these new development will lead into world expansion of civilian nuclear power program. There is a high hope for a larger contribution of nuclear power in the future in the U.S. and in the world.

Nuclear technology is one of the few economically viable base load electricity generation technologies with no direct greenhouse gas emissions. Due to high energy content in nuclear fuel, the mass or volume of fuel and the associated waste is small. There exist opportunities for energy security as procurement and storage of large inventory of nuclear fuel is possible unlike other energy technologies. With the implementation of breeder reactor technology, sustainable energy generation is also possible.

However, for these benefits to be fully realized and appreciated, the concerns with the use of nuclear technology must be properly addressed. Due to its capital cost intensive nature, requirement for a large manpower support, and very-long term nature of the resulting radioactive contamination, establishing a civilian nuclear program requires a long-term financial and political commitment. As the sustainable development of human society requires energy security, responsible use and management of nuclear technology will be increasingly important in the future.

[35] Near Term Deployment Group, "A Roadmap to Deploy New Nuclear Power Plants in the United States by 2010," Volume I Summary Report, Prepared for the U.S. Department of Energy, Office of Science and Technology, 2001.

[36] US DOE Nuclear Energy Research Advisory Committee, A Technology Roadmap for Generation IV Nuclear Energy Systems, GIF-002-00, December 2002.

2 What is Nuclear Engineering Research?

Nuclear engineering is the most stupendous scientific achievement. Nuclear engineering research has many important practical applications and is much more than a single field. It is a building block of modern human's prosperity.

The nuclear engineering field has started with the discovery of neutron in 1932 by Chadwick, a prominent researcher in Great Britain. Few scientists before him tried to understand the outcomes of the experiments and published papers in which they explained the neutrons as very strong gamma radiation coming out of nuclei. Bethe and Irene Joliot-Curie have been performing the series of experiments but missed the correct explanation[37]. The spectacular use of neutrons opened many new prospects for the advancement of humanity: in generating the power (through fission process), medical treatments, material science and technology, imaging, probing; neutrons are still representing the ultimate probing tool in basic science. Research reactors are devices that produce neutrons of all kind of energies (properties) useful in science, medicine and industry. One such a reactor of very small power exists at Purdue University where students learn how to operate and control the reactor and what the nuclear reactor is, how neutrons are produced, and how fission sustains itself in a safe and secured way.

Nuclear engineering research nowadays is focused at many applications toward advancement of human life. Here are some examples:

- Over 440 nuclear power plants operate around the world generating the electricity, a commodity of modern humanity. For example, France produces over 80% of electricity from nuclear sector; USA produces 22%, while Japan produces close to 40%. The only other way of massive sustainable production of electricity was fossil fired power plants and hydro potential. Coal pollutes, oil reserves depletes, hydro is a local resource and not every country in the world has this potential. The newest research is focused at finding most optimized nuclear power reactors, with promoted economical and nonproliferation aspects of the designs.
- Cancer treatment using neutrons was foreseen as soon as neutron was discovered. The so called neutron capture therapy (NCT) is used for the most severe cases of brain and skin cancer. Recently with the advanced knowledge of cell biological functions, the NCT finds its application in the treatment of lung, liver, head and neck cancers, as well as recent novel research in its application for the metastasized breast cancers. Fast neutron therapy shows encouraging results for advanced head and neck cancers, cervical node metastases, oropharynx and salivary gland cancer.

[37] Read this beautiful biography about Irene Joliot-Curie: Robin McKown, *She Lived for Science Irene Joliot-Curie*, Julian Messner, Inc. New York, 1961

- Neutrons can easily identify almost every naturally occurring chemical element. Neutron imaging is a technique to detect the content of the object. Recently research is focused at applying the fast neutron imaging in detecting the chemical composition of the sections in the body and thus detecting cancer even before it is formed anatomically. The most interesting research is directed toward breast cancer detection.
- Neutron microscopy and neutron/gamma ray tomography are new imaging tools offering better contrast for biological samples[38].
- Cold neutron beams are researched as powerful tools for studying the cell membrane phenomena. Neutrons are non-destructive and highly penetrable and thus provide incomparable ways of probing matter.

2.1 Importance of an Engineer's Role in Nuclear Engineering Research

In nuclear engineering research we *never guess*! In the discipline of nuclear engineering, surgery, and cancer treatment and diagnostics, one wrong guess can cause tremendous non-reparable negative consequences and even fatalities to one person or to the public at large. We always teach our students that in nuclear engineering it is of the outmost importance not to guess the answer to the question asked, line of action as a response to the problem or to arbitrarily comment or conclude. As we have learned from Chapter 1 the mistakes made in nuclear engineering field caused unnecessary outcomes that influenced negative public perception toward advancement and use of nuclear technology.

The ethics represents the prosperous ground for better tomorrow. It holds for nuclear technology and nuclear engineering research more than for any other discipline or section of human life.

Whenever you do research in nuclear engineering related topics:

- Never guess the results and make it work that way
- If you find you made a mistake previously, admit as soon as you find out and report it; this way you are ethical and you learn
- If you see others make mistake help them understand it
- If you see others make intentional mistake help them not do that
- Discuss freely every question you have in the workplace, with your adviser, your colleges, your boss
- Read about new research in nuclear engineering to always know where your research stands and make sure your research is ethically right
- Learn about misconduct in research and what that means
- Learn about the policy regarding the misconduct in research at the University you are a student, or in a company your are an employee

[38] http://www.physorg.com/news599.html

2.2 Two Themes in Addressing Ethical Responsibilities of Nuclear Engineering Researcher

The two themes selected to exercise your understanding of the role of ethics, meaning of ethics, and specifics of nuclear engineering research are both imaginatory. The first theme reflects a common situation in which a student (un)consciously involves himself in a plagiarism; the second theme presents a misconduct in nuclear engineering research and the consequences it generated. In order to proceed to these two themes it is important to understand the definitions and the meaning of the misconduct in research in general. The good summary is given in the following two boxes.

> **https://www.cu.edu/policies/Academic/misconduct.html**
>
> **DEFINITION OF MISCONDUCT:**
>
> Under this policy "research misconduct" shall include but shall not be limited to:
>
> (1) **Fabrication, falsification, plagiarism and other forms of misappropriation of ideas, or additional practices that seriously deviate from those that are commonly accepted in the research community for proposing, conducting, or reporting research.**
>
> (2) **Material failure to comply with federal and University requirements for the protection of researchers, human subjects, or the general public or for ensuring the welfare of laboratory animals.**
>
> (3) **Failure to adhere to other material legal requirements governing the field of research.**
>
> (4) **Failure to comply with established standards regarding author names on publications.**
>
> (5) **Retaliation of any kind against a person who reported or provided information about suspected or alleged misconduct and who has not acted in bad faith.**
>
> The definition of research misconduct does not include honest error or honest differences in interpretations or judgments of data. Moreover, the definition contained in this policy is not intended to override or contradict provisions of other regulations or policies, in particular those policies governing human research subjects and animal welfare. A finding of a substantive violation of specific policies in these areas will also be considered misconduct under this policy.
>
> **The University will undertake reasonable efforts to protect those persons who make good faith allegations regarding research misconduct.** Institutional actions engaged in pursuant to this policy shall be conducted in a way that preserves confidentiality to the maximum extent possible, unless this would be inconsistent with protecting public health and safety.

http://facpub.stjohns.edu/~roigm/plagiarism/ghost%20authorship.html

Ghost Authorship

Ghost authorship occurs when a written work fails to identify individuals who made significant contributions to the research and writing of that work. Although in recent times this unethical practice is typically associated with the pharmaceutical and biomedical device industry, the term is also applicable in a number of other contexts. For example, in academic contexts, it is widely recognized as cheating to have someone other than the named student author write a paper that is then submitted as the student's own. Perhaps with some exceptions (e.g., speech writers), ghost authorship is ethically unacceptable because the reader is mislead as to the actual contributions made by the named author.

- Academic Ghost Authorship

A not uncommon form of academic dishonesty that has probably always existed is to have someone else other than the student (a friend or relative), complete an assignment or write a paper. Several Internet sites now exist that, in addition to making available copies of papers that have already been written, they also provide custom-written papers, including doctoral theses. The customer (i.e., student) specifies the topic and other requirements for the paper and, for a fee, a staff writer for the service will supply a custom-written product. For an eye-opening account of how this practice works even before the proliferation of on-line paper mill sites, I refer the reader to Whitherspoon (1995)'s personal account as a Ghostwriter. Situations in which authors, whether students or professionals, find themselves in need of extensive external assistance with their writing can also raise some interesting ethical dilemmas. For example, consider the doctoral candidate who, because of limited writing skills, relies heavily on an individual or editorial service resulting in that individual making substantial editorial changes to the writing of the thesis. Such a situation may be acceptable as long as the named author indicates in a byline or acknowledgement section the full extent of others' assistance. This, however, is not always done and one of the reasons is that such acknowledgement may reflect negatively on the author as possibly indicating that s/he does not have the necessary skills expected of a doctoral candidate. By mischaracterizing or by not acknowledging altogether the high level of assistance received, students falsely portray a level of academic competency that they truly lack. In instances in which doctoral students anticipate relying on outside individuals to help with the writing of a thesis or even term paper, it is strongly recommended that they confer with their thesis committee and supervisor to determine the accepted parameters of such assistance and to fully disclose the nature of the assistance received.

- Professional Ghost Authorship

In the literary world ghost authorship is most often associated with celebrity-authored works in which a celebrity, together with a skilled writer produce written products, such as an autobiography or a sort of "tell all" book. Although much of the writing may be done by the ghost writer, his/her contributions are not always acknowledged and, consequently, in those instances the reader may be mislead into believing that the celebrity is the sole author of the work. In the biomedical sciences ghost writing has become particularly problematic (see Ngai, Gold, Gill, & Rochon, 2005). For example, in a typical scenario, a pharmaceutical or medical device company will hire an outside researcher with known expertise in the company's line of products (e.g., antidepressants) to write an "balanced " review of their product. To facilitate the write-up of the paper, the company furnishes the expert with a draft of the paper that had already been prepared by a ghost author employed by the company. And, as it often happens in these types of cases, the resulting paper ends up portraying the product in a more favorable light than in reality it might deserve. The extent of ghost contributions can range from the initial draft framing of a manuscript to the complete or nearly complete write-up of the paper (see the distinction made by Chalmers as cited by Altus, 2006). In either case, the main concern is the extent to which the writing influences the reader toward a particular product or point of view rather than presenting an unbiased position or data. In the past few years, several articles and editorials have condemned the practice as ethically questionable. For example, the World Association of Medical Editors has produced a position statement, which considers ghost authorship dishonest and unacceptable.

2.2.1 Nuclear Engineering Class

Case Example: Presenting Research Results

Academia should be a bastion of ethical behavior. As a student in nuclear engineering field, you should be a voice in promoting ethically high standards in education, research and learning. But the differences in ethical standards due to cultural differences or different learning practices need to be recognized.

The case example is described as follows:

> A foreign student is asked to write a paper in which he is supposed to summarize his research. His research represents the continuation of the research previously done by another student working with his adviser. A student is new in the country, not accustomed yet to the environment and with a possible lack of understanding the policy in research misconduct. His knowledge of English language is not good and he has difficulties to write and speak fluently and correctly. His research summary presented in the form of written paper contained:
> 1. copied sentences from other papers
> 2. copied sentences from the paper written by his adviser and previous student
> 3. copied figures from different sources
>
> all without referring to the sources.

Ethical Responsibilities in Presenting Research Results

How do we characterize this example and how we may resolve it?

- It is easy to conclude by reading the definitions of misconduct in research that the direct plagiarism is involved in this student writings. However, if this is the first time that student wrote by copying and not writing a proper reference, adviser may spend time explaining the rules regarding the misconduct and make sure the student understood it well. If this repeats after a warning, it is considered to be a conscious attempt by student to cheat and the proper measures are to be taken.
- Why this common example is so specific for nuclear engineering? This case represents one of many examples of how the advancement and globalization through internet and fast means of information storage and transfer may mislead the individuals in believing it is difficult to find the source of their plagiarized work. Nuclear engineering community is very small and it is very easy therefore to find the copied work. In addition, nuclear engineering research may involve experimental data and by stealing the results and presenting as yours, you may involve yourself in bigger problems. Read next example to understand how misconduct in research can affect your life carrier.

Interesting questions to think about regarding this example are:

- Would the outcome be different if this case takes place in different countries (e.g., Italy, Germany, China, Japan, Australia or South Africa)?
- Would the concern be different if this took place in different times (e.g.,1907)?

- What would happen if the adviser did not read the paper and just sent it for publication?

2.2.2 Nuclear Engineering Innovation

Case Example: Misconduct in Nuclear Engineering Research

The following imaginative case example is specific to nuclear engineering field because it involves the use of radioactive sources.

The case example is described as follows:

I. Professor “A” and his graduate student publish a paper claiming a new way of achieving conditions for safe, reliable and sustainable process. If confirmed by independent scientists and proved by theoretical and numerical models, the work would most likely be considered for the Nobel Prize.

II. Professor “B” and his graduate student reproduce the experiment from the work of professor “A”. They find that the experiment is not achievable and that a secret use of some sort of radioactive source explains the signal produced in the experiment. Professor “B” and his graduate student perform detailed Monte Carlo modeling to show that the secret use of certain radioactive isotope is the reason of the claim by Professor “A”.

III. Professor “B” does not publish his findings but he is sure that someone in Professor “A”s Laboratory uses the radioactive source to enhance the experimental results. He does not know, professor “A” is aware that his student did it, or professor “A” himself did it.

Ethical Responsibilities and Potential Outcomes

How do we characterize this example and how we may resolve it?

- **Science is a continuous self-testing process**. It is expected from every true scientist to constantly review his/her own work, test and retest the experiment and theory and openly communicate the findings. There is an obvious misconduct in research but what is specific here for the nuclear engineering:
  - Any misuse of radioactive sources, change of the radioactive sources locations in the laboratory without telling to the occupants, inappropriate storage of radioactive sources: this is all against the policy and law.
  - Most unethical issue is the possibility of exposing other people to radiation without telling them. You may argue that the personal radiation detectors would show increased exposure. But every additional radiation exposure must be justifiable. Sometimes people would not question the additional exposure as long as the dose received is below the permissible limits.
  - Use the analytical or numerical approach to determine the safe distance from various radioactive sources found in University Laboratories that will give a small radiation dose to a student. What do you learn from this small exercise?

- **Analysis of the misconduct in research**:

- If professor “A” consciously fabricated the results the misconduct in research policy is to be applied. Read the policy and write what is the line of action required according to that.
- If professor “A”s student fabricated the results and you are another member in the laboratory who saw this, read the misconduct in research policy and write what are you supposed to do?
- If both, professor “A” and his student fabricated the results of their experiment by using the radioactive source what would be the line of action the University should follow?
- Should professor “B” publish his results and his assumption of the misuse of the radioactive source in professor “A”s experiment? Read the policy and write what in your opinion professor “B” is supposed to do.

Interesting questions to think about regarding this example are:

- Would the outcome be different if this case takes place in other countries (e.g., Italy, Germany, China, Japan, Australia or South Africa)?
- Would the concern be different if this took place in different times (e.g., 1941 or 1970’s)?