الملتقى العلمي

الاستخدام السلمي للطاقة النووية وأثره على الأمن البيئي


ورقة علمية بعنوان

الطاقة النووية وحماية السلامة

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**Abstract:** With finite, diminishing world supplies of natural resources (fossil fuels), nuclear power represents a vital technology needed to meet current and future world energy requirements and to support and sustain expanding national economies. Our mature nuclear engineering technologies provide redundant safety features; nuclear reactors are designed to anticipate, minimize, and mitigate thousands of failure or accident scenarios. Operated and maintained properly under strict regulatory compliance, nuclear power plants emit negligible particulate and gaseous radioactive emissions. Radiation doses to workers and to members of the offsite general public continue to decrease as plant operators implement quality procedures and emphasize the importance of safety culture. The public will not accept technologies that place people at risk for significant radiation exposure from unanticipated events. Nuclear power plant accidents, such as Chernobyl and the catastrophic earthquake and tsunami that destroyed the Fukushima-Daiichi complex in Japan, have greatly increased the fear of radiation and have lessened public confidence in the safety of nuclear power plants. Achieving the nuclear safety imperative means that nuclear power plant owners, operators, employees, and federal regulators must continue working toward higher levels of safety compliance to re-establish public confidence and trust. National leaders and regulators must also acknowledge sound technological solutions and facilitate the safe storage, packaging, transportation, and permanent, long-term disposal of spent nuclear fuels and radioactive waste. The Health Physics Society is highly committed to improving nuclear power safety, minimizing environmental impacts, and reducing worker and general public exposures to radiation and radioactive materials so that electrical
energy can be produced safely and efficiently for the greater public benefit.

INTRODUCTION

The world needs additional nuclear power to meet energy requirements for the 21st century. Nuclear energy delivers a clean, non-fossil energy source to secure our economic future and to meet increasing demands for electrical generating capacity. Nuclear energy helps the world to preserve finite, non-renewable oil and gas resources. Nuclear power plants are engineered to produce electricity reliably in all seasons and weather conditions. Plants represent highly engineered facilities having a combined total of 3,500 reactor-years of operating experience with no radiation-related health effects.

The nuclear industry, regulatory authorities, and the Health Physics Society share a commitment to worker safety and environmental protection. Our mature nuclear engineering technologies provide redundant safety features; nuclear reactors are designed to anticipate, minimize, and mitigate thousands of failure or accident scenarios. Operated and maintained properly under strict regulatory compliance, nuclear power plants emit negligible particulate and gaseous radioactive emissions.

Nuclear Safety an Imperative

We define the term imperative as a necessity, as something that demands attention or action, and an unavoidable obligation. The word imperative signifies something vitally important, essential, critical, urgent, and indispensable. It can also mean compulsory, obligatory, or mandatory. Imperative is the opposite of optional. In the context of nuclear power and public perceptions, radiation safety is the most important factor in successful plant operation.
Nuclear energy is needed to sustain vibrant and growing economies. Therefore, our mature nuclear engineering technologies provide redundant safety features and are designed to anticipate thousands of failure or accident scenarios. The public will not accept technologies that place people at risk for significant radiation exposure from unanticipated events. The U.S. regulatory approach is based on an updated, risk-informed framework designed to anticipate events that could compromise safety.

Achieving the nuclear safety imperative means that nuclear power plant owners, operators, employees, and federal regulators must continue working toward higher levels of safety compliance to re-establish public confidence and trust. National leaders and regulators must also acknowledge sound technological solutions and facilitate the safe storage, packaging, transportation, and permanent, long-term disposal of spent nuclear fuels and radioactive waste.

**Role of the Health Physics Society**

The Health Physics Society is an international scientific organization of about 5,000 professionals who specialize in radiation protection, including scientists, engineers, radiation safety officers, university professors, administrators, military technical specialists, physicians, government officials and regulators, lawyers, and retirees. The Society represents the leading source of expertise in radiation safety and publishes the scientific journal *Health Physics*. The Society prepares position statements and advises government decision-makers and regulators on important issues in radiation protection appertaining to the nuclear power industry, the medical field, and industrial uses of radiation and radioactive sources. We support our members who work in the nuclear power industry and help regulate the industry, including nuclear fuel cycle and radioactive waste disposal facilities. We encourage better scientific understanding of radiation and its effects through basic and applied research, detection and measurement technology, scientific exchange through conferences and meetings,
education and training, and disseminating reliable information to the public. We recognize that nuclear safety is an imperative (not an option) to regain public confidence in the ability of the nuclear industry produce electricity safely and to adequately deal with radioactive wastes.

**Working Relationship with the U.S. Nuclear Regulatory Commission**

The Health Physics Society supports the mission and responsibilities of the U.S. Nuclear Regulatory Commission, with our common objective of helping to ensure the safety of nuclear power plants and the safe use of nuclear byproduct materials for beneficial purposes. Leaders of the Society meet twice each year with the NRC commissioners and their senior staff. Several senior NRC staff hold membership in the Health Physics Society, participate in Society activities, and contribute to our educational and public outreach.

**Economic Factors**

The expansion of nuclear power in the U.S. has not met previous expectations, due largely to cost, regulatory changes, and nuclear accidents. New nuclear power plants are expensive, capital-intensive construction projects. Despite high initial costs, financial analyses by universities, electrical companies, and federal agencies show that electricity produced by nuclear power plants can be competitive with other modern options for electrical energy generation. The U.S. produces electricity mainly from coal (37%), natural gas (30%), and nuclear (19%), with additional power provided by hydroelectric dams, oil-fired plants, and wind energy (13%). Natural gas prices fluctuate with considerable price uncertainty and instability. Abundant natural resources have helped uranium prices to stabilize. Nuclear plants have become more efficient. These factors make the country’s nuclear option among the lowest-cost source of electricity. The economics of nuclear power have necessitated relicensing of nuclear plants beyond original lifetimes. Several older plants in the U.S. have closed permanently:
Kewaunee Power Station, Crystal River Nuclear Plant, San Onofre Units 2 and 3, and Vermont Yankee in the U.S. A period of low pricing for natural gas has altered some plans for new nuclear power plant construction.

Five new nuclear power reactors are currently under construction in the U.S., including Watts Bar 2 (online in 2015), Vogtle 3 and 4 (online in 2017 and 2018), Summer 2 and 3 (online in 2017 and 2018). The ability of the nuclear industry to move forward with new plant construction, particularly during a period of low natural gas prices, shows the confidence of the electrical utilities, regulators, politicians, and general public in the economic viability and safety of nuclear power as a reliable energy source for the future. However, these and all existing facilities must operate at a higher level of safety.

**CURRENT ISSUES IN RADIATION PROTECTION**

Radiation doses to workers and to members of the offsite general public continue to decrease as nuclear power plant operators implement quality procedures and emphasize the importance of safety culture (USNRC 2012). The Health Physics Society views three current issues in radiation protection as having substantial importance for nuclear safety:

1. Ensuring adequate measures to protect nuclear workers and the general public from radiation exposures
2. Reducing the risk of nuclear accidents and dealing appropriately with the consequences of past nuclear accidents, and
3. Providing adequate facilities and procedures for the safe, permanent disposal of radioactive waste and used nuclear fuel

The Society has worked with regulators and nuclear industry representatives to achieve goals associated with these issues. The nuclear industry has established performance goals and standards for the nuclear industry has established higher standards for improving radiation safety at power plants, optimizing high-dose tasks during
required maintenance, and establishing measures for preventing unplanned doses during unanticipated events. The current regulatory philosophy involves a risk-informed approach.

**Basic Radiation Safety Regulations and Dose Limits**

The current regulatory framework under Title 10 of the U.S. Code of Federal Regulations, Part 20, continues to adequately protect the health and safety of nuclear industry workers, the public, and the environment. The current regulations were largely based on radiation protection guidance developed by the International Commission on Radiological Protection (ICRP) during the 1970s. Many aspects of radiation protection philosophy and associated dose limits have changed in the last 40 years. The Health Physics Society supports current efforts by the U.S. Nuclear Regulatory Commission to update its radiation protection regulations under 10 U.S. Code Part 20 to achieve better alignment with the 2007 Recommendations of the International Commission on Radiological Protection (ICRP) given ICRP Publication 103. The ICRP has recommended an occupational dose limit of 20 mSv, compared to the previous limit of 50 mSv.

However, many elements of ICRP Publication 103 propose measures that exceed what is needed to provide adequate protection. *Therefore, the Health Physics Society believes that current occupational radiation safety standards and regulations are sound and adequately protective of radiation workers* (Position Statement PS013-1, 2012). The current dose limits represent an acceptable level of potential risk and do not represent a level that will be unsafe if exceeded. The proposed reduction of occupational dose limits does not represent evidence that the earlier dose limits were inadequate. Average doses received by radiation workers have been, and continue to be, below current dose limits. The most reliable studies of the effects of radiation exposure at the low levels received by occupational workers have not been able to detect adverse health effects associated with lifetime exposures smaller than approximately 0.1 Sv. The Society believes the implementation of
radiation safety standards and regulations has been responsible and adequate in providing for a safe industry, taking into account changes in occupational work practices over the last 40 years. Current standards incorporate the philosophy of as low as reasonably achievable (ALARA) in radiation safety work practices. The application of ALARA is founded in the professional judgment of radiation safety managers and personnel and should not be used to determine whether a radiation safety program is adequate by comparison with other programs. Implicit within regulations is the expectation that workers and employers implement a safety culture, recognizing unsafe conditions and ceasing operations that are not safe.

**Dose to Lens of the Eye**

Currently, U.S. regulations under 10 CFR Part 20 limit annual occupational exposures to the lens of the eye to 150 mSv (15 rem) per year (10 CFR 20.1201). The U.S. Nuclear Regulatory Commission has asked for comments from stakeholders about possibly lowering the occupational exposure limit for radiation to the lens of the eye, because the International Commission on Radiological Protection has recommended a lower limit of 20 mSv (2 rem) per year, averaged over defined periods of five years, with no single year exceeding 50 mSv (5 rem). The current U.S. limit is seven times higher. Further, the International Atomic Energy Agency has incorporated the new limits into the revision of the *International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources* (2011).

Protecting the eyes against the effects of ionizing radiation is designed primarily to prevent the formation of cataracts, and the sensitive part of the eye for this health effect is the lens. The radiation dose to the eye is defined by 10 CFR 20.1003 as the lens dose equivalent at a tissue depth of 0.3 cm. Cataract formation is a near-term *deterministic* effect, with severity increasing with radiation dose to the lens. At doses above the deterministic threshold level, the severity of cataract formation increases
with dose, but the radiation-induced incidence below the threshold dose is believed to be essentially zero. The current position of the Health Physics Society (Pryor, 2011) states that the current dose limits adequately protect workers, and that any new data on biological effects of radiation should be examined for their potential impact on improving safety. The Society maintains that the new scientific data on radiation effects for the lens of the eye need to be examined more carefully.

We understand that relatively high doses to the lens of the eye (above 2 Gy) can result in serious lens opacities leading to cataracts. New studies indicate that acute exposures of about 0.5 Gy are sufficient to cause cataracts. For fractionated and protracted exposures, new studies also suggest a threshold value of about 0.5 Gy to the lens of the eye, but this is for lens opacities rather than cataracts that impair vision. Dosimetry to comply with the proposed changes in dose limits is not well developed and entails substantial uncertainty. Mechanisms by which radiation might cause cataracts following low dose fractionated exposures are not well known. Because occupational doses consist mainly of fractionated exposures over time (not acute exposures), the Society recommends that these new data be studied more carefully before regulatory changes are made.

**Preventing Nuclear Accidents and Dealing with Accident Consequences**

Despite the scientific and engineering accomplishments of the nuclear industry, three catastrophic reactor accidents (Three Mile Island, Chernobyl, and Fukushima Daiichi) have severely shaken the public confidence in nuclear power as a current and future energy source. The public fear of radiation has increased. The release of radioactivity from these accidents and increased radiation doses to members of the general public have resulted in a loss of trust in industry’s ability to safely operate nuclear power facilities.
The nuclear safety imperative requires greater vigilance to the potential causes of severe nuclear accidents. The March 2011 events at Fukushima-Daiichi showed that highly unanticipated natural disasters must be taken into account during reactor siting. Following the Richter-scale 9.0 earthquake in Japan, a 15-meter ocean tsunami disabled the Fukushima power supply, emergency power supplies, control systems, and cooling system operations. Eleven nuclear reactors at four power plants in the region were operating at the time of the earthquake, and all reactors shut down automatically when the quake hit. Subsequent inspection showed no significant damage to any of the reactors from the earthquake. The operating units which shut down were Tokyo Electric Power Company's (Tepco) Fukushima Daiichi 1, 2, 3, and Fukushima Daini 1, 2, 3, 4, Tohoku's Onagawa 1, 2, 3, and Japco's Tokai, comprising a total electrical generating capacity of 9377 MWe net. Fukushima Daiichi units 4, 5, and 6 were not operating at the time, but were affected by the disaster. The main problem initially centered on Fukushima Daiichi units 1-3. Unit 4 became a problem on day five. Units 1, 2, and 3 reactor cores melted during the first three days of the accident, releasing radioactive materials into air and water. Four nuclear power plants were destroyed. After cooling the reactors, the major tasks have been to prevent further radioactive materials release and to deal with extensive contamination caused by the multiple-unit accident. A full analysis of the accident and its consequences is beyond the scope of this presentation.

The human death toll from the earthquake and tsunami exceeds 19,000. Despite the accident, the World Health Organization has not documented any deaths or sickness due to radiation. Over 100,000 residents were evacuated from their homes. About 1 million homes and buildings were destroyed. Flooding covered 560 square kilometers.

According to the World Nuclear Association, the original design basis tsunami height was 3.1 m for Daiichi based on assessment of the 1960 Chile tsunami. The Daiichi nuclear plant was therefore constructed about 10 meters above sea level, with the seawater pumps at 4 m above
sea level. The nearby Daini plant was built 13 m above sea level. In 2002 the design basis was revised to 5.7 m above sea level, and the seawater pumps were sealed. In March 2011, tsunami heights coming ashore were about 15 m, and the Daiichi turbine halls were under 5 m seawater until levels subsided; Daini was less affected. The maximum amplitude of this tsunami was 23 m at point of origin, about 180 km from Fukushima. The tsunami countermeasures taken when Fukushima Daiichi was designed and sited in the 1960s were considered acceptable in relation to the scientific knowledge available at that time. Since 1960, new data showed the potential for a large earthquake and resulting major tsunami off the Japanese coast. However, new data did not result in any major corrective action by either the plant operator, Tepco, or by government regulators (Japanese Nuclear and Industrial Safety Agency). All nuclear power plants worldwide are today engaged in studies to ensure adequate protection against both seismic events and flooding.

The consequences of the 2011 earthquake and tsunami have had devastating effects on the people and economy of Japan. Recovery and cleanup will cost $30 billion (U.S.) or more, and require upwards of 30 years to complete.

**Used Nuclear Fuel Management and Permanent Geologic Repository**

Although nuclear waste management and used fuel disposal represent significant public concerns, from an engineering perspective, the nuclear industry has developed modern technologies for encapsulating and disposing of nuclear wastes. The current problem for waste disposal in the U.S. is political, rather than technical.

Under U.S. law (Nuclear Waste Policy Act, 1982), the Department of Energy should have already transferred more than 28,000 metric tons of reactor fuel from nuclear power plants to a permanent geologic repository plus an additional 3,000 metric tons each subsequent year. Congress assigned responsibility to the U.S. Department of Energy to
locate, construct, operate, and close a repository for the disposal of spent nuclear fuel and high-level radioactive waste. The U.S. Environmental Protection Agency was directed to establish scientifically based health and safety standards to protect the public from releases of radioactive materials from the repository, and the U.S. Nuclear Regulatory Commission was required to develop the regulations governing construction, operation, and ultimate closure of a repository. An Office of Civilian Radioactive Waste Management was established in the U.S. Department of Energy to implement the Act.

Generators and owners of spent nuclear fuel and high-level radioactive waste were required to pay the costs of disposal of such radioactive materials. The waste program, which was expected to cost billions of dollars, would be funded through a fee paid by electric utilities on nuclear-generated electricity. Although funds have been collected from nuclear power utilities, the government has not completed the required permanent disposal facilities.

The Yucca Mountain site in the western State of Nevada was selected through a comprehensive scientific process. Considerable funds were spent developing the Yucca Mountain deep geologic repository. However, after objections by Senator Reid and others from the State of Nevada, the Executive Branch of the federal government halted plans to complete and license this facility. The Office of Civilian Radioactive Waste Management was dissolved in 2010. Consequently, the U.S. government does not currently have a workable program for managing used nuclear fuel from commercial nuclear energy facilities and high-level radioactive waste from the government’s defense and research activities. Failure to adequately deal with nuclear waste creates additional health and safety concerns. The nuclear power industry and the Health Physics Society support completion and licensing of the Yucca Mountain repository. We believe that the inability of the U.S. government to complete and license a permanent deep geologic repository for used nuclear fuel has increased the long-term costs and
has lengthened the timescale needed for waste management and permanent geologic disposal.

The challenge for nuclear power is to overcome political obstacles to technologically proven solutions and optimal disposal sites for used nuclear fuels.

Used nuclear fuel comprises small uranium pellets stacked inside alloy fuel rods. Until the U.S. federal government establishes an adequate program to dispose of these materials, nearly all commercial used fuel must be stored safely and securely at the reactor sites in steel-lined concrete pools filled with water, or in airtight steel or concrete-and-steel containers. The Health Physics Society supports development of temporary facilities for storing used nuclear fuel in willing states while progress is made on the permanent geologic repository.

REGULATORY PHILOSOPHY: RISK-INFORMED APPROACH

Current regulatory decision-making in the U.S. accounts for risk factors that focus licensee and regulatory attention on design and operational issues commensurate with their importance to public health and safety. Technology risk assessment. The risk-informed approach asks four basic questions:

- What can go wrong?
- How likely are the accident scenarios?
- What are their consequences?
- Which systems and components contribute the most to risk?

Under former decision-making using a “deterministic” approach, regulators and operators performed risk analyses based on largely unquantified probabilities, design-basis accident scenarios, “defense in depth” provisions, and wide safety margins. However, these traditional methods often imposed extra or unnecessary regulatory burdens on licensees and could be incomplete in terms of scope. Consequently,
decision-making next relied on a more complex risk-based approach involving quantified probabilities and thousands of accident sequences. Although this approach was more realistic, it did not and could not include all potential accident scenarios. Today, the U.S. Nuclear Regulatory Commission takes a balanced or “risk-informed” approach that combines the traditional and risk-based approaches through a deliberative process. The risk-informed approach incorporates an assessment of safety significance or relative risk to ensure that the regulatory burden imposed by an individual regulation or process is appropriate to its importance in protecting the health and safety of the public and the environment (Delaney et al., 2005). The regulators use probabilistic risk assessment to estimate risk by computing real numbers to determine what can go wrong, how likely is it, and what are its consequences. Application of probabilistic risk assessment can help ensure appropriate barriers, controls, and personnel; prevent, contain, and mitigate exposure to radioactive material according to hazards, relevant scenarios, and associated uncertainties; and ensure that risks from the failure of barriers and controls, including human errors, are maintained acceptably low.

**Radiation Protection Goal Achievement**

Data for occupational radiation exposures at U.S. nuclear power plants show consistent, long-term reductions in collective worker doses over

![Figure 1. Average collective worker doses at U.S. pressurized water reactors relative to the 2015 industry goal.](image)
the past 14 years (Figure 1 for pressurized water reactors and Figure 2 for boiling water reactors). Collective doses achieved at pressurized water reactors are about one-half those at boiling water reactors.

![Figure 2](image)

**Figure 2.** Average collective worker doses at U.S. boiling water reactors relative to 2015 industry goal.

**Fuel Performance and Integrity**

Nuclear fuel integrity and performance are important for limiting undesirable releases of radioactive materials into the environment. One measure of progress toward achieving fuel integrity is the percent of nuclear reactors that achieve zero fuel failures during a given year. Figure 3 shows the percent of nuclear power reactors in the United States that achieved zero fuel failures for years 2006 through 2013 compared to the industry goal of 100 percent (zero fuel failures).

Fuel failures have several different causes: corrosion and crud, mechanical fretting wear (foreign material such as a piece of wire vibrating against the fuel rod surface), and pellet cladding interactions or stress when fuel pellets interact with the inner cladding. The total number of fuel failures, for both boiling water reactors and pressurized water reactors, was substantially lower in 2013 than during previous decades. The nuclear industry continues to study improved fuel designs and alloys for reducing and eliminating fuel failures.
System Safety Performance

Nuclear power plants are designed and constructed with multiple safety systems and backup power supplies so these systems are available, if needed, even when maintenance is being performed on a similar system or component. The three principal backup safety systems are two main cooling systems and the backup power supplies for responding to unusual events. Each system has an availability goal of almost 100 percent due to maintenance and testing. Figure 4 shows the percent of nuclear power plants in the U.S. with backup safety systems that met the industry goal for safety system performance by year from 2006 to 2013.
Numerical Basis for Radiation Protection Goals

In the U.S., the regulatory standards for radiation protection are based on risk estimates and probabilities of early and latent cancer mortality risks from nuclear plant operations, and apply to an individual living near the reactor. Under the standard, the risk of early death or from cancer should not exceed 0.1 percent of the background risk from natural radiation. The numerical technical bases are $5 \times 10^{-7}$/year for early death (at the site boundary to 1 mile) for an average resident, and $2 \times 10^{-6}$/year for death from cancer (at the site boundary to 10 miles) for an average resident. Under normal operations, U.S. nuclear power facilities produce negligible off-site releases of radioactive materials (particulates and gases), resulting in negligible calculated radiation doses to the off-site general public. According to the Nuclear Energy Institute (2014), “Studies by the U.S. National Cancer Institute, the United Nations Scientific Committee of the Effects of Atomic Radiation, the National Research Council’s BEIR VII study group, and the National Council on Radiation Protection and Measurements all show that U.S. nuclear power plants cause no harm to people in neighboring communities.” This positive performance record reflects well on the quality engineering of nuclear power plants, excellence in operational performance, and technical support from the radiation protection community.

CONCLUSIONS

The Health Physics Society is highly committed to improving nuclear power safety, minimizing environmental impacts, and reducing worker and general public exposures to radiation and radioactive materials. While it is important to maintain radiation protection standards consistent with international guidance, the Society maintains that current standards provide adequate radiation protection, and does not endorse or advocate for reductions in the occupational dose limit from to 20 mSv per year, or reductions in the occupational dose limit for lens of eye. We note continuous improvement by the U.S. nuclear industry regarding collective worker doses, fuel performance, and system safety reliability.
and availability. Improved safety measures implemented and supported by a strong safety culture will help ensure that electrical energy from nuclear power plants can be produced safely and efficiently for the greater public benefit.

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REFERENCES


selecting and constructing a permanent underground repository for high-level radioactive waste. The Act also required planning for monitored retrievable facilities for temporary (50-100 year) storage before permanent disposal or spent fuel reprocessing.
