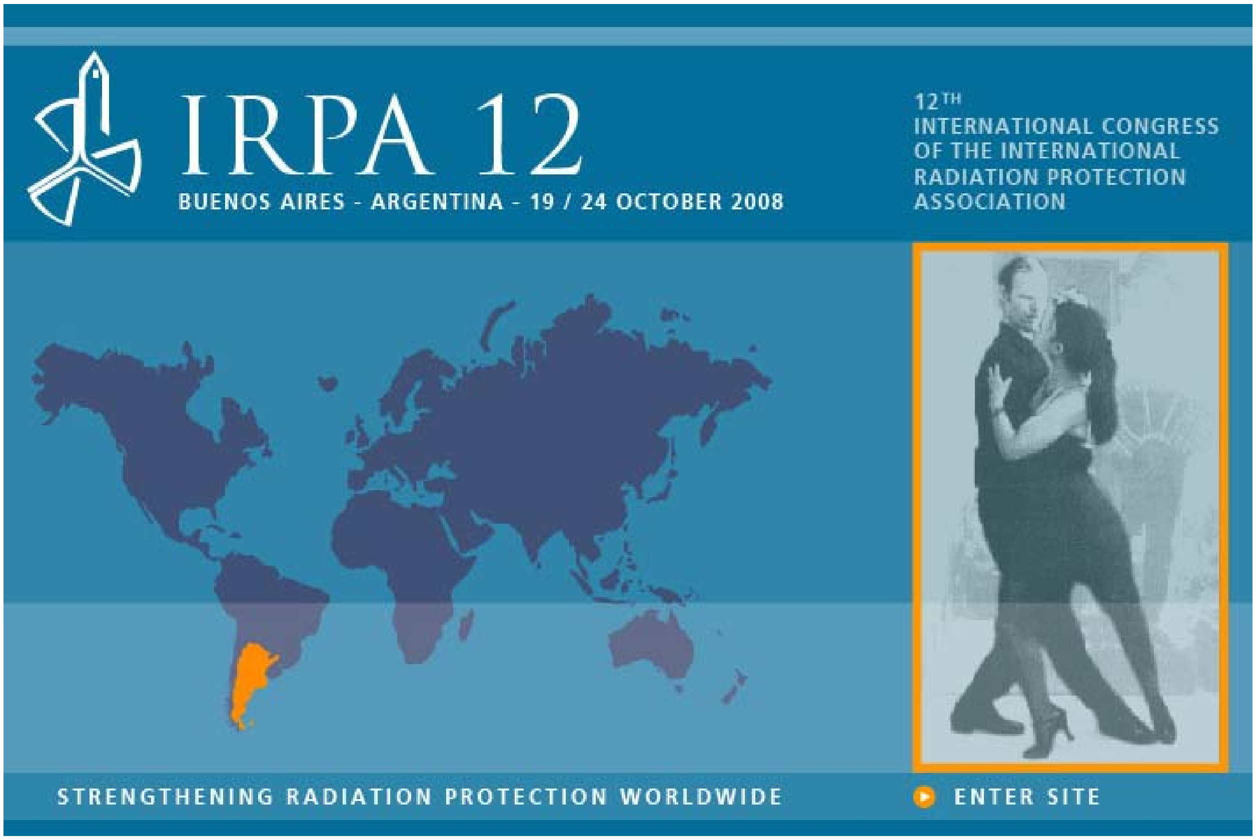

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Who's Empowered to Protect? How Are They Empowered? What Do They Need to Know?

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Abstract. In 1996, the author published a paper entitled "Ten Principles and Ten Commandments of Radiation Protection." That paper recognized that radiation protection consists of far more than "time, distance, and shielding," notions that can be acted on by workers to manage external irradiation, but that are of little use for the prevention of intakes of radioactive materials. The paper encompassed the entirety of radiation protection, including actions that may be taken at many levels (commandments) and the principles on which they are based. This paper expands the previous paper by further specifying who can take actions, where their empowerment comes from, and what knowledge is needed to act appropriately. Who is empowered to take radiation protection actions? Depending on the circumstances, it can be workers, managers, health care professionals, regulators, legislators, law enforcement personnel, first responders, and/or individual members of the public. How are individuals or groups empowered to take protective actions? Their empowerment comes from many sources, including self-preservation; education and training; administrative procedures; posting and labelling; provision and use of personal protective equipment; design, creation, and maintenance of engineered barriers; medical care; treaties, laws, regulations, recommendations, and guidance. Examples of hitherto unknown radiological hazards being discovered and subsequently managed are provided. The basis for radiation protection action is knowledge of the radiological situation. What do individuals or groups need to know to choose the correct course of action? The answers to this question differ as widely as approaches to managing radiation risks listed in the 1996 paper. This paper ends with a systematic analysis of information needs for radiation protection.

KEYWORDS: Radiation protection philosophy; competent authority; guidance; principles of radiation protection; individual action; individual responsibility; fallout; Chernobyl; radiological attack; nuclear attack.

1. Introduction

In recent years, I have witnessed or participated in situations for which the traditional radiation protection paradigm of the IAEA, ICRP, and many other organizations doesn't work well or doesn't work at all. This paper will frame these shortcomings using a list of all radiation protection activities previously published as "Ten Principles and Ten Commandments of Radiation Protection"[1]. That paper did not address *who* was empowered to act in response to the commandments, *how* the actor or actors are empowered, or *what* they needed to know to act appropriately. The paper addresses situations in which approaches to radiation protection are needed that are outside of the traditional legal and organizational scope of radiation protection.

2. History of hazards and their management

History reveals an increasing awareness of health hazards and slowly evolving attitudes towards their control. Organized, regulated, government-enforced workplace safety and protection always followed significant loss of life and limb, becoming widespread only in the 20th century of the Common Era. Outside of the workplace, disease prevention, health protection, and health promotion have not fared as well. Ionizing and non-ionizing radiation have been added to the list of hazards to human health. The history of evolving awareness of radiation hazards is well-documented, and provides examples of denial of the hazards, opposition to protection and controls, followed by step-wise improvements in workplace safety and protection of worker health. Similar phenomena have occurred for exposures of the public.

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As awareness of the need for radiation protection in the workplace developed, recognition of the need for radiation protection standards evolved. As chronicled by Moeller[2], over time, the focus of radiation protection standards shifted from one goal to several goals. These were

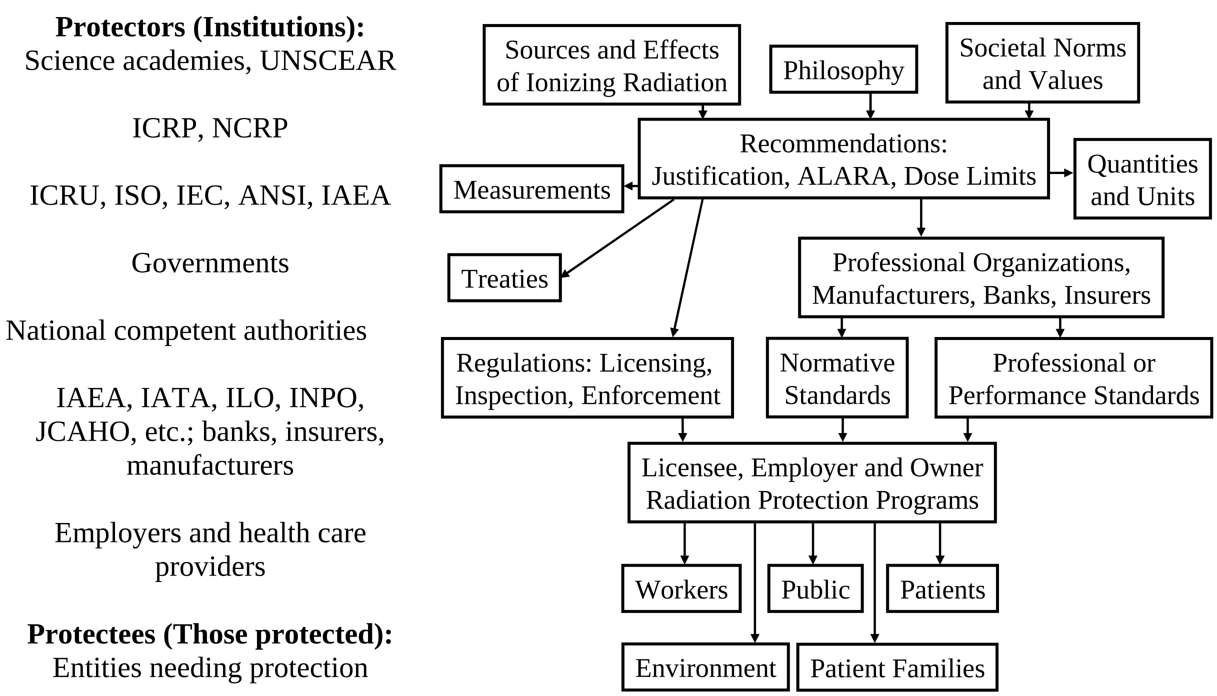
- prevention of early deterministic effects from acute exposures
- prevention of late deterministic effects from chronic or protracted exposures
- limitation of probability of heritable ill-health (often referred to as genetic effects)
- limitation of probability of leukaemia and later solid tumours

Despite the prevalence of radium-laden consumer products, medical misadventures such as thorium contrast media for diagnostic radiology, and some very high-dose medical diagnostic procedures, recognition of need for radiation protection of the public, the patient, the family of the patient, and the environment emerged later. Real action against high levels of radon decay products in indoor air didn't occur in the USA until the mid-1980s following the discovery of a house with radon concentrations of about 100,000 Bq/m^3. And even today, members of the public may elect to have whole-body computed tomography (CT) scans, resulting in whole-body absorbed doses of several tens of milligrays.

3. The Traditional Paradigm of Radiation Protection

A paradigm of radiation protection that I call "the traditional paradigm" has emerged in the more than 100 years since the discovery of ionizing radiation and radioactive materials, as illustrated in Figure 1. The traditional paradigm is presented in detail below. The terms "protector" and "protectee", a neologism for the person or entity being protected, are used in the same way as the familiar terms "employer" and "employee."

Figure 1. The "traditional paradigm" of radiation protection is a top-down system in which functions (in boxes on the right) are provided by institutions (listed on the left at the approximate level of their function) to protect people and the environment. All acronyms are explained in the text.



The traditional paradigm is a system in which institutions participate in a hierarchical system to provide protection to people and the environment. At the top of the figure, the institutions include national science academies and organizations such as the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) that provide scientific input into the process.

The next level consists of international or national commissions such as the International Commission on Radiological Protection (ICRP) or the US National Council on Radiation Protection and Measurements (NCRP) that make recommendations on radiation protection. Such entities draw on scientific knowledge, philosophy, and societal norms and values for their work.

Recently, the ICRP has published the latest in its series of recommendations on radiation protection[3]. The ICRP has developed "principles" that underlie its *system* of radiation protection, namely, justification, optimization, and limitation[3]. These principles provide the foundation for the ICRP's rationale for decisions to use a technology or not, to determine the appropriate level of resources to be used for protection, and to limit risk to any individual by establishing dose limits that should not be exceeded if an adequate degree of protection is to be provided. The essential ideas behind the principles have withstood the test of time, despite the ongoing need for improvements in detailed expressions of their application[3]. The ICRP has elucidated important concepts for protection of workers, members of the public, patients who are irradiated or to whom radioactive materials have been administered, families of such patients, and the environment[1].

At the level of recommendations, many specific ideas are needed, such as radiation quantities and units, and guidance and procedures for measurements. Input to these needs is provided by a variety of organizations, including the International Commission on Radiation Units and Measurements (ICRU), the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC), the American National Standards Institute (ANSI), and the International Atomic Energy Agency (IAEA). There are many others. These organizations and institutions also play roles in normative standards, as well as in professional and performance standards.

The IAEA develops international consensus approaches to regulation and standards that can be implemented. The IAEA traditionally interprets the ICRP's recommendations as basic safety standards[4], a form more suitable for regulations. IAEA did this for the previous ICRP recommendations[5]. IAEA's standards are expressed in terms of quantities that can be measured, whereas the ICRP traditionally has not felt the need to be quite so practical[6].

The IAEA's documents are subsequently recast by government entities such as the European Union[7] as model regulations for implementation by competent authorities (legally constituted regulatory agencies with training and expertise in regulation of technologies involving radiation and radiation protection). In the USA, the Environmental Protection Agency (EPA) fulfils this role, considering, in addition to ICRP and IAEA, the recommendations of the NCRP.

Governments play at least two distinct roles in the process: entry in to treaties and other international agreements, and the creation and operation of competent authorities. The former role is discussed below.

The regulator or competent authority must adopt and amend documents such as IAEA Basic Safety Standards to meet its unique needs. The competent authority generally establishes regulations requiring licensing of uses of radiation sources. The competent authority must also establish mechanisms for inspection, control, and imposition of penalties for non-compliance. Finally, the competent authority may have to collect revenue to support its existence. In the author's own country (USA), agencies such as the

[1] See the ICRP website for examples: http://www.icrp.org.

Nuclear Regulatory Commission, the Department of Energy, the Environmental Protection Agency, the Department of Defense, the Department of Transportation, the Occupational Health and Safety Administration, the Mine Safety and Health Administration, the Postal Service, the 50 States (in the sense of "United States"), and other governmental agencies are required to regulate sources of ionizing radiation.

There are other de facto regulations in many countries, which have impacts on the practice of radiation protection equivalent to the impacts of regulations. In the international arena are the IAEA, the International Air Transport Association (IATA), and the International Labour Organization (ILO), among others. In the United States, there are the Institute for Nuclear Power Operations (INPO), which exerts significant influence on the nuclear power industry, and the Joint Commission on the Accreditation of Healthcare Organizations (JCAHO) which exerts strong influence of uses of radiation in medicine. In addition, there is a role for banks, insurers and manufacturers in setting standards in cases where competent authorities are unable or unwilling to act.

At the bottom of the institutional hierarchy in the traditional paradigm are the radiation protection programs of licensees. Licensees include employers, industries, nuclear utilities, and healthcare organizations. For most, radiation exposures to people and the environment are an unwanted by-product of their activity, while for health care providers, deliberate exposure of human beings is undertaken to provide diagnostic or therapeutic benefit. In either case, the implementation of radiation protection guidance and regulations occurs at this level.

Over the years, the system embodied in the traditional paradigm has often functioned to protect humankind and the environment from the harmful effects of radiation with improving efficacy, although with enormously increasing costs. The protectees are often divided into groups such as workers, members of the public, patients, families of patients, and the environment. However, the traditional paradigm is untested for radiological or nuclear attack, and has failed in countless situations involving ignorance, malice, deliberate deception, or when there is no licensee or regulated entity. These failings indicate a need for an alternative paradigm in which the protectees, at least the human ones, become empowered and informed so that they can become engaged in their own protection.

4. How Can People and the Environment Be Protected from Ionizing Radiation?

Before discussing who is empowered to protect, it is important to examine the "how" of radiation protection at all levels, so that one can understand in a concise fashion what actions can be taken by various "actors" in the great scheme of radiation protection.

To provide simple guidance on what actions people or institutions can take to provide radiation protection, the author published a paper entitled "Ten principles and ten commandments of radiation protection"[1]. The paper encompassed the entirety of radiation protection, including directions for what to do (commandments) and the principles on which those commandments are based. Since these principles and the actions to implement them are fundamental to the thesis of this paper, they are repeated in Table 1. Since 1996, the only addition has been the phrase "stay upwind" in commandment 2.

A recent example illustrating commandments 1 and 2 is shown in Figure 2.

5. Who is empowered to protect, and how are they empowered?

Who is empowered to take radiation protection actions? Depending on the circumstances, it can be the United Nations (UN) and governments; legislators and lawmakers; regulators; licensees and managers;

Table 1: Principles of radiation protection and actions to implement those principles. Implementing actions are expressed as "commandments," in both familiar and technical language, so there is no uncertainty about what to do. Unlike "time, distance, and shielding," these principles and commandments apply to radiation fields *and* radioactive materials.

Principle	Commandment (familiar)	Commandment (technical)
1. Time	Hurry (but don't be hasty)	Minimize exposure time, minimize intake time
2. Distance	Stay away from it, or upwind of it	Maximize distance; stay upwind
3. Dispersal	Disperse it and dilute it	Minimize concentration, maximize dilution
4. Source reduction	Make and use as little as possible	Minimize production and use of radiation and radioactive materials
5. Source barrier	Keep it in	Maximize absorption (shield); minimize release (contain and confine it)
6. Personal barrier	Keep it out	Minimize entry into the body of radiation and radioactive materials
7. Decorporation (internal and surface irradiation only)	Get it out of you and off of you	Maximize removal or blocking of materials from the body (after intake or skin contamination)
8. Effect mitigation	Limit the damage	Optimize exposure over time and among persons; scavenge free radicals; induce repair
9. Optimal technology	Choose best technology	Optimize risk+benefit+cost figure; consider non-radiation technologies
10. Limitation of other exposures	Don't compound risks (e.g., don't smoke)	Minimize exposures to other agents that may work in concert with radiation (e.g., genotoxic agents or agents that may cause initiation, promotion, or progression of tumors)

Figure 2: The recent ISO graphic illustrating commandments 1 and 2, minimize exposure time and maximize distance, or "hurry" and "stay away from it."

law enforcement personnel and first responders; health care professionals; workers; and/or individual members of the public.

5.1 The United Nations and governments

Governments enter in to treaties and other international agreements, and to the extent that the prevention of attack with nuclear weapons is a radiation protection activity, governments so far have been successful. They have also succeeded in limiting atmospheric and ocean releases of radioactive materials from nuclear weapons testing, doubtless a major success in radiation protection. Other UN or government actions taken to prevent radiological or nuclear attack may legitimately be construed as radiation protection actions. These include actions to prevent the acquisition and use of nuclear weapons by rogue states, actions to prevent illicit trade in special nuclear materials and radioactive materials, actions to prevent special nuclear materials and radioactive materials from crossing borders, and actions to keep nuclear weapons from space.

The UN is empowered by its member states. The governments of those states empower themselves.

5.2 Legislators and lawmakers

Legislators and lawmakers enable radiation protection by creating competent authorities, by providing economic incentives and disincentives for various radiation technologies, and by outlawing certain activities that may lead to radiation exposure of people or contamination of the environment. Legislators can also fund research and development through government agencies.

Depending on the form of government, legislators and lawmakers are empowered by their governments' constitutions, the citizens of their countries, by traditional or historical governance, or by military power. Legislators and lawmakers can be disempowered from protecting occupational and public health and the environment by political and economic forces or by strategic interests of their governments.

5.3 Regulators

Regulators issue radiation protection policy, regulations, guides for compliance, and technical documents that support compliance. Regulators issue licenses, perform inspections and review records to determine compliance with regulations, issue citations and penalties (ranging from press releases to fines to criminal prosecution), and collect fees. It is almost unheard of for a regulator to congratulate a licensee on a job well done.

Regulators are empowered by laws that establish their agencies and scope of their responsibilities. Regulators can be disempowered from protecting occupational and public health and the environment by lack of funding, judicial interference, or corruption.

5.4 Licensees and managers

Of all the institutions and organizations discussed here, organizations holding licenses and management personnel within a licensee organization have the most direct impact on occupational radiation protection, and on protection of the environment. Licensees and managers can protect through the establishment of policy, education and training, procedures and administrative controls, radiological engineering and process control, optimization of radiation protection through "as low as reasonably achievable" (ALARA) programs, inspections, provision of radiation control technologies in the form of engineered controls and personnel protective equipment (PPE), programs and plans to respond to accidents and emergencies, radiological and personnel monitoring, recordkeeping, reporting, waste disposal, and decommissioning.

Licensees and managers are empowered and motivated by regulatory agencies and their institutions.

5.5 Law enforcement personnel and first responders

Law enforcement personnel, including customs and border patrols, have a significant role in detection and interdiction of materials for radiological or nuclear attack, as well as responses to accidents, emergencies, and inadvertent exposures to unknown radiation sources. In the event of accident or attack involving radiation exposure of workers and members of public, first responders and law enforcement personnel can help to prevent those portions of potential radiation exposures that are subject to control, and triage and direct people to health care providers.

Law enforcement personnel and first responders are empowered by their agencies and legal mandates.

5.6 Health care professionals

Health care professionals can protect people by decontamination or decorporation (for example, debridement of contaminated wounds, surgical removal of radioactive artefacts, or chelation therapy), actions that actually reduce dose. Health care professionals can also reduce the effects of dose or committed dose through control of infection, blood transfusions and bone marrow transplants, and other clinical means. Clinicians can also ameliorate late health effects such as cataracts and cancer through therapies such as lens implants and cancer therapies such as surgery, chemotherapy, and radiation therapy.

Health care professionals are empowered by their organizations and their professional oaths. They can be disempowered by fear of liability, institutional policies, fear for personal safety, and duty to family.

5.7 Workers

Workers can protect themselves and co-workers from radiation by choosing safe behaviours, following safe procedures, obeying postings, using PPE, and practicing good hygiene. Indeed, workers rely on co-workers to be safe in high radiation situations[8]. If workers are taught not just "time, distance and shielding," but all 10 principles and commandments of radiation protection as they apply to their jobs, and as they relate to both limiting external irradiation and intakes and ontakes[2] of radionuclides, then they can do a better job protecting themselves. For some workers, such as members of air crews or astronauts exposed to radiation from space, very few radiation protection options exist.

Workers are empowered to protect by their own self-interest, their responsibility to work safely, their co-workers, the safety culture of their employers, and regulations (including whistleblower protections). They are disempowered by ignorance, apathy, fear, lack of a safety culture, lack of good work practices, lack of engineered controls or PPE, fear of retribution for whistle blowing, lack of preparation, haste, and carelessness.

5.8 Individual members of the public

Members of the public can take many of the same actions to protect themselves and their families as can workers and managers, but have additional choices. They can choose where to live; choose to remediate dwellings if they have high radon levels; make appropriate risk-management lifestyle choices (such as not smoking); choose not to have needless medical exposures (e.g., elective whole-body CT scans in the absence of symptoms, or repeated radiological exams by different health-care providers); choose to prepare for and respond to accidents and emergencies by sheltering in place or evacuating and by stocking and using potassium iodide if needed. Examples of self-protection are presented later. In some circumstances, individual and familial protection needs may not be met by the traditional system of radiation protection.

[2] By analogy with "intake," "ontake" refers to contamination of the outside of the body. Ontake means 1) an event in which a person is externally contaminated; or 2) the activity that is taken on, that is, the amount of dermal or other contamination.

Members of the public are empowered to protect by their own self-interest, their responsibility to keep their families safe (especially parents caring for children), by education and training, by accurate information about the radiological situation and what actions they can take. They are disempowered by ignorance, apathy, and fear.

5.9 Protectors, protectees, and protection principles in play

Table 2 shows a list of those institutions or organizations doing the protecting ("protectors"). For each protector, the list of potential protectees is checked, and a list of radiation protection principles that protectors can implement. A few examples of such protection are given below.

Table 2: Tabulation of protectors, protectees, and radiation protection principles that protectors can apply.

	Protectees: Who or what is protected?					What principles are used in protection?									
Protectors: Who is doing the protecting?	Workers	Public	Patients	Families of patients	Environment	Time	Distance	Dispersal	Source Reduction	Source Barrier	Personal Barrier (PPE)	Decorporation	Effect Mitigation	Optimal Technology	Limitation of other Exposures
United Nations and governments	x	x	x	x	x				x						
Legislators ad lawmakers	x	x	x	x	x				x					x	
Regulators	x	x	x	x	x				x					x	x
Licensees and managers	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Law enforcers, first responders		x	x	x	x	x	x	x	x	x		x	x		
Health care professionals	x	x	x	x				x	x	x		x	x	x	x
Workers	x	x	x	x	x	x	x	x	x	x	x	x			x
Individual members of the public		x	x	x	x	x	x	x	x	x	x	x	x	x	x

6. What do the protectors need to know?

First and foremost, protectors must have quantitative, or at least qualitative, knowledge of the potential or actual radiological situation. Protectors must understand what principles and commandments they are empowered to enact, and what resources are needed for successful protection. Protectors must be able to judge what is reasonable, in the sense of optimization, and when protective action is unnecessary. Protectors may have to account for individual differences in either susceptibility to effects of radiation (e.g., age, sex, and pregnancy status are significant risk factors) or need or desire for protection (e.g., triage following an accident or radiological attack may result in differing efforts for decontamination).

In the USA during the 1950s, a natural extension of protection against aerial bombardment experienced during World War II was the establishment of a civil defence organization to protect against a nuclear attack. This organization provided training, information, and radiological survey instruments to organizations and individuals. The civil defence program empowered individual members of the public to protect themselves and their families in situations to which the government could not conceivably respond effectively. One hallmark slogan of that era taught to schoolchildren was “duck and cover,” meaning that if there were a bright flash, children were to duck under furniture and cover their eyes. Besides its protection against flash blindness and flying debris, this was excellent advice that could be life-saving for individuals given that initial nuclear radiation persists for 10 or more seconds.

7. Case studies

Below are three examples of situations where the traditional radiation protection system was incomplete or absent.

7.1 Unlicensed radium

During the late 20th century, the author was hired to radiologically characterize a building contaminated with ^{226}Ra that wasn’t licensed or otherwise regulated. The building was deserted, and the only protection available was whatever I brought with me and chose to use. I was the employer and sole employee. While no records or reporting were required, I engaged in personnel monitoring and radiation measurements and reassured myself through subsequent bioassay and in vivo counting that I had not received significant exposures. There was no institution to protect me; I was the protector and protectee.

7.2 Wastewater treatment

The author helped develop a plan for a wastewater treatment plant to respond to wastewater heavily contaminated due to a radiological attack[9]. Management personnel at the plant had been frustrated during an emergency exercise that no guidance was available on whether the plant should treat the wastewater, resulting in contamination of the plant and potential exposures to workers, or cause the wastewater to bypass the plant and be discharged, untreated, into the bay. While under US regulations an employer has an obligation to provide a radiologically safe workplace, the regulations were written only for non-accident, foreseeable situations. Nonetheless, we were able to craft a list of commandments and actions for both management and workers. The most serious threat to those workers remains an undetected dispersion of radioactive materials. Aside from direct radiation, the wastewater worker’s existing commandment “no hands above the collar,” intended to protect from microbiological hazards, helps prevent ingestion and facial ontakes. The wastewater treatment utility found itself in a radiation protection vacuum.

7.3 Protecting family following Chernobyl

Vitaly Eremenko’s covert efforts to protect his newborn granddaughter and his family from radioactive contamination released during the Chernobyl accident have been documented[10]. Dr. Eremenko was forced to create a surreptitious radiation protection program for himself and his family due to secrecy following the accident. As a trained radiological physicist, he was able to implement the principles of time, distance and direction, source reduction, source barrier, personal barrier, and enhanced decorporation. All of his actions were based on knowledge of the radiological situation based on measurements he made. Again, there was no institution providing protection, only the efforts of a lone individual.

8. Conclusions

There are situations in which the traditional radiation protection paradigm of institutions protecting people and the environment doesn't work or doesn't work well. By analyzing protectors and protectees in the context of radiation protection principles and commandments, a need for improvement in informed individual protection actions has been demonstrated.

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REFERENCES

[1] STROM, D.J., Ten principles and ten commandments of radiation protection. Health Phys., 70 (1996) 388-393. Available by permission of the journal at http://www.pnl.gov/bayesian/10Principles.pdf.

[2] MOELLER, D.W., History and perspective on the development of radiation protection standards, in: W. K. Sinclair (Ed.), NCRP Publications, Bethesda, Maryland, 1989, pp. 5-23.

[3] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION (ICRP), Recommendations of the ICRP. ICRP Publication No. 103, Ann ICRP, 37 (2007).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA), International basic safety standards for protection against ionizing radiation and for the safety of radiation sources. Safety Series No. 115. 1996. Vienna, International Atomic Energy Agency.

[5] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION (ICRP), 1990 Recommendations of the ICRP. ICRP Publication No. 60, Ann ICRP, 21 (1991).

[6] STROM, D.J., Name those quantities. Radiat. Prot. Dosimetry, 108 (2004) 183-185.

[7] COUNCIL OF THE EUROPEAN UNION, Council Directive 96/29/EURATOM of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation, Official J. of the European Communities, 39 (1996) 1-114.

[8] QUADREL, M.J., BLANCHARD, K.A., LUNDGREN, R.E., MCMAKIN, A.H., MOSLEY, M.T., STROM, D.J., U.S. Department of Energy workers' mental models of radiation and chemical hazards in the workplace. PNL-9467; 1994. Richland, Washington, Pacific Northwest Laboratory.

[9] HICKEY, E.E., STROM, D.J., Technical basis for radiological emergency plan annex for WTD emergency response plan: West Point Treatment Plant. PNNL-15163 Vol. 3. 2005. Richland, Washington, Pacific Northwest National Laboratory.

[10] EREMENKO, V.A., DROPPO, JR., J.G., A personal experience reducing radiation exposures: protecting family in Kiev during the first two weeks after Chernobyl, Health Phys, 91 (2006) S39-S46.