An Evaluation of Radiation Exposure Guidance for Military Operations: Interim Report

Institute of Medicine

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An Evaluation of Radiation Exposure Guidance for Military Operations

Interim Report

Committee on Battlefield Radiation Exposure Criteria
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Medical Follow-up Agency
Institute of Medicine

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Preface

In May 1995, the Office of the Surgeon General (OTSG) of the U.S. Army contacted the Institute of Medicine, requesting that it consider studying the health and ethical implications of conducting military operations in low-level nuclear environments. The request was prompted by the Surgeon General's participation with the North Atlantic Treaty Organization (NATO) in the development and standardization of procedures and equipment for detection, measurement, removal, and disposal of low-level radioactivity.

The IOM responded in July 1995 with a proposal to establish an expert committee to undertake the study, which was funded in September 1996. The committee's charge was developed in conjunction with the OTSG and consisted of two major tasks. In the first, we were to review draft NATO radiation protection guidance from a technical perspective and suggest improvements. The Army was most interested in receiving that review as quickly as possible. This report fulfills that desire. Our second task will be to consider broader issues of law and ethics.

We have included sufficient technical background in this first report that it can stand alone. Nevertheless, the reader should recognize that without the law and ethics component, the committee's work is incomplete. The second report, due a year from now, will expand the current report to consider the ethical, moral, and legal basis from which soldiers are exposed to and protected from radiation. The development of a complete system of radiation safety for the soldier will require not just the technical information discussed in this report but also the ethical foundations to be presented in the next.

Making this report useful to the widest possible audience within the Army has been a challenge. The technical basis of radiation safety is complex and given to its own jargon. On the one hand, we have made every effort to be as precise as possible in the discussion of background material. On the other hand, we have made some difficult choices to leave out some details that, if included, would have compromised clarity. We hope that diverse groups from radiation safety specialists to combat soldiers will find this report useful.

FRED A. METTLER, JR., CHAIRMAN

Acknowledgments

The committee and staff are grateful to LTC Carl A. Curling (Medical Nuclear, Biological, and Chemical Staff Officer) at the Office of the Army Surgeon General. As our project officer, he worked to explore the scope of the overall project, organized briefings and materials for the committee, and acted as a liaison to other military staff. We also acknowledge the important work of LTC John Bliss (International Chairman, NATO Working Group 2 on Low-Level Radiation) and LTC William J. Klenke, LTC Curling's predecessor, in initiating and supporting this project. COL David Jarrett (Director, Military Medical Operations Office, Armed Forces Radiobiology Research Institute), CPT Marc Umeno (Nuclear Medical Science Officer, US Army Nuclear and Chemical Agency), MAJ Debra Schnelle (Manager, Medical Health Physics Program; US Army Center for Health Promotion and Preventive Medicine), MAJ Brett Armstrong (Chief, Nuclear, Biological, and Chemical Sciences Branch; US Army Medical Department Center and School), CAPT Richard LaFontaine (US Navy), and LCDR Phillip Liotta (US Marine Corps) presented useful background material and perspective to the committee. Others whose efforts enhanced this report are Institute of Medicine-National Research Council staff—Claudia Carl, Mike Edington, and Linda Kilroy; and consulting editors—Peter Slavin and Beth Gyorgy.

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Summary

During the Cold War, the United States Army established radiation dose limits and controls for soldiers based on a scenario of global nuclear war (NATO, 1986; HQDA, 1994). Battlefields were expected to be heavily contaminated. Radiation protection standards and controls for soldiers were based on criteria that maximized immediate survival and the ability to continue the combat mission. The upper bounds of the dose limits were at the threshold for development of radiation sickness.

In the post Cold War setting, military scenarios involving radioactive contamination rarely reflect global nuclear war, but more often consider limited nuclear exchanges, terrorist actions using improvised nuclear devices, conventional explosives employed as a means of disseminating radioactive materials, or nuclear power plant accidents. In these scenarios, radioactive contamination would be more restricted geographically and the immediate risk to the health of a soldier might be much lower. Except under very rare circumstances, radiation doses under this scenario would be well below the lethal level, yet they could be above occupational dose limits that are applied to civilian workers (CFR, 1991).

The Supreme Headquarters, Allied Powers Europe (SHAPE) of the North Atlantic Treaty Organization (NATO) recognized a need to plan for potential radiation exposure of military forces in Europe during the peacekeeping mission to Bosnia. In response, SHAPE staff developed the Allied Command Europe (ACE) Directive Number 80-63, *ACE Policy for Defensive Measures against Low Level Radiological Hazards during Military Operations*. For convenience, we refer to this document as the *ACE Directive*. This embodiment of NATO's guidance for the protection of its military forces from radiation is the subject of this report.

At the request of the U.S. Army Surgeon General, the Institute of Medicine has convened an expert committee to evaluate these guidelines from scientific and ethical perspectives. This report, Part I of this committee's efforts, focuses on the scientific merit of the current NATO guidance by responding to the three-part charge:

1. Do the presently proposed NATO guidelines (dose limits, documentation, and control measures) follow generally accepted U.S. national limits and recommended guidelines for radiation protection of occupational and emergency workers?
2. Are these NATO guidelines reasonable from a scientific viewpoint?
3. How could the guidelines be improved?

The committee will report next year, in Part II, its follow-on deliberations on other critical factors, including ethics, risk perception, record keeping, training, communication, and decision making, with additional scientific information as necessary. The Army requested that the committee complete its technical review of the ACE Directive as quickly as possible, concentrating on the broader issues of ethics and law in the second year of the study. The technical recommendations we now present do not yet include these extremely important considerations.

Not surprisingly, however, we found each technical point to be associated with numerous considerations that involve societal, organizational, and personal values. The committee will spend its next year of research and deliberation in providing the Army Surgeon General with cogent and practical guidance that includes and reflects this broader philosophical context. Because of this, the current review must be considered a work in progress; it will not be complete until the final report adds the broader perspective.

In answering its charge, the committee reviews the basic principles of radiation physics and radiobiology and presents an overview of current practices in radiation protection in the civilian sector and in the Army. From this basis the committee comments on the technical aspects of the NATO guidance and makes several recommendations.

This report is about radiation protection, the aims of which are (a) to prevent the occurrence of acute health effects (e.g., cataracts in the eyes and radiation sickness) and (b) to ensure that all reasonable steps are taken to reduce the induction of potential long-term effects (e.g., cancer) to a level that is acceptable to society (ICRP, 1991a).[1] To achieve these aims, radiation doses to individuals and populations must be measured and controlled. These doses (related to the amount of radiation energy deposited in tissue per unit of mass) typically are

[1] See Chapter 3 of this report for a more complete description of radiation protection.

expressed in the international units millisievert (mSv) or milligray (mGy),[2] or in the traditional units, the rem and rad, respectively.

Radiation doses that exceed a minimum (threshold) level can cause undesirable effects such as depression of the blood cell-forming process (threshold dose = 500 mSv, 50 rem) or cataracts (threshold dose = 5,000 mSv, 500 rem). The scope and severity of these effects increases as the dose increases above the corresponding threshold. Radiation also can cause an increase in the incidence, but not the severity, of malignant disease (e.g., cancer). For this type of effect, it is the probability of occurrence that increases with dose rather than the severity. For radiation protection purposes it is assumed that any dose above zero can increase the risk of radiation-induced cancer (i.e., that there is no threshold). Epidemiologic studies have found that the estimated lifetime risk of dying from cancer is greater by about 0.004% per mSv (0.04% per rem) of radiation dose to the whole body (NRC, 1990).

Radioactive sources can expose the body from outside (external doses, e.g., when a diagnostic x ray is taken), or from inside (internal doses, e.g., when radioactive materials are inhaled, ingested, or enter through wounds). Gamma and x-ray radiations (and, to a lesser extent, beta radiation) are the primary contributors to external doses. Alpha and beta radiations are much more important contributors to internal doses.

Control measures to reduce or limit exposure to radiation must consider the circumstances and environment of the exposure. In discussing the influence of scenario on radiation controls, we use the ICRP (1991a, 1993) nomenclature —"intervention" and "practice." A practice is an intentional activity in which the practitioner is routinely at risk of radiation exposure (e.g., the duties of x-ray technicians in hospitals and nuclear power plant workers). An intervention, by contrast, is an action taken to reduce radiation exposure, often by responding to an accident (e.g., the actions of firefighters who responded to the Chernobyl accident). A practice is characterized by well-defined radiation sources and work procedures; an intervention, by great uncertainty in both.

The Army has previously published guidance for control of doses from routine occupational exposures to radiation and from those associated with nuclear war. The ACE Directive is an encouraging step in developing control measures for other situations. We realize that the Directive was meant for a specific mission (Bosnia) and that the Army recognizes its limitations. The improvements recommended by the committee should be viewed as constructive and in no way diminish the significant progress that the Army has made toward the control of the complete spectrum of radiation hazards on the battlefield and in nonwartime situations. While the ACE Directive is useful as a basis for establishing guidelines to protect soldiers from the adverse effects of radiation, the committee recommends that it be revised to assure completeness and clarity.

[2] Throughout this report (except in quotations) the committee has chosen to use the millisievert and milligray as units of effective dose and absorbed dose, respectively. Traditional units are given in parentheses.

UNDERLYING PHILOSOPHY OF THE ACE DIRECTIVE

The committee recommends that the Army:

1. **Provide soldiers the same level of radiation protection as civilians working in similar environments**. The ACE Directive appears to manage all military missions involving radiation exposures as interventions. While this is clearly appropriate for many missions (e.g., emergencies, radiation accidents, and operations involving hostile action), other missions can more properly be treated as routine practices, thereby affording more complete control of the radiation exposure. Missions amenable to control as practices might include security details, decontamination of vehicles, and other scenarios in which hostile action is not expected.
2. **Develop and state an explicit radiation protection philosophy that defines missions as falling under the framework of either a practice or an intervention**. *Practices* would be subject to modified requirements of the Army's existing occupational radiation protection program. It is likely that the situation in Bosnia would fall into this category. Under the committee's recommendations, soldiers would be considered radiation workers if they were assigned military duties that have the potential for radiation exposures that could result in doses in excess of the International Commission on Radiological Protection limits for the public (ICRP, 1991a) —1 mSv per year. A revision of the existing exposure guidance in the ACE Directive would govern those situations that are of an emergency nature and would be managed as *interventions*. In both cases, keeping doses as low as reasonably achievable would still be of primary importance.
3. **Clearly state in the policy paragraph of the subsequent versions of the ACE Directive the definitions adopted for practices and interventions in the necessary military context.** The procedures that follow the policy statement should address practice and intervention separately. It would seem reasonable for the commander to have the authority to determine which of these frameworks to follow based upon the military mission.

TERMINOLOGY IN THE ACE DIRECTIVE

The committee recommends that the Army:

4. **Not use the term *low level* to describe the radiation dose range of 50–700 milligray (mGy) (5–70 rad).** *Low level* may be an appropriate descriptor when comparing these doses to those that may be experienced from the detonation a nuclear weapon. In the broader context of radiation protection, however, *low level* clearly implies much lower doses.
5. **Use terms other than *no risk* and *normal risk* for the risk state categories labeled RES 0 and RES 1A in the table of exposure guidance in Annex A of the ACE Directive.** To describe any nonzero dose as *no risk* is incon

sistent with current international positions on the effects of radiation. Likewise, the term *normal risk* incorrectly implies *no additional risk* to that from natural background radiation exposure, even though such exposures are considered to contribute very small, possibly negligible, health risks.

6. **Avoid the term *radiological hazard* when describing the exposure of soldiers to radiation, unless the hazard refers to a specific detrimental effect**. For most cases in the ACE Directive *radiological hazard* simply means *radiation*.

PROSPECTIVE RISK ASSESSMENTS

The committee recommends that the Army:

7. **Develop requirements for measuring, interpreting, and responding to airborne and surface contamination (particularly that containing alpha and beta emitters). Guidance should define levels of alpha and beta contamination that would trigger use of protective equipment and actions.** The ACE Directive gives only cursory consideration to this topic and the terminology used to describe the instrumentation necessary for the detection and measurement of radioactive contamination is not clear.
8. **Reconsider its absolute requirement that soldiers wear protective equipment within an exclusion zone as defined in the ACE Directive** . The decision to use protective equipment should be based on the potential for personal contamination with radioactive materials, externally or internally. To require respiratory protection regardless of the existence of an airborne hazard may be counterproductive to completing the mission in a timely and effective manner.
9. **Make a clear distinction between military intelligence estimates and radiation risk estimates.** It is unclear, in the *Intelligence* procedures section (NATO, 1996, §1-3.a.), whether *risk (high or low)* refers to (a) intelligence assessments of the *likelihood* of radiation contamination or (b) the magnitude of measurable levels of radiation contamination.
10. **Develop explicit requirements to define when individual radiation monitoring is required in the field.** The guidance on whether a soldier could enter a low-level contaminated area without individual dose monitoring is vague. It would be reasonable to require individual dosimetry for all incursions into an exclusion zone where radioactive contamination is likely.

DOSIMETRY REQUIREMENTS IN THE ACE DIRECTIVE

The committee recommends that the Army:

11. **Review its dosimetry capabilities and determine if they are adequate to support the use of the Operational Exposure Guidance in the ACE Directive.** In order to manage soldier exposures according to the ACE Directive, all soldiers would have to have dosimeters that can measure doses as low as 0.5 mGy (0.05 rad).
12. **Increase specificity of the dosimetry program guidelines in subsequent versions of the Directive (e.g., provide specific guidance on the capabilities of monitoring devices and equipment).** The committee considers radiological monitoring and dose estimation for individuals, outside the occupational environment, as areas that require significant attention by the Army.
13. **Not assume, as the ACE Directive does, that internal doses will be zero because respiratory protection will be used**. Soldiers may receive an internal dose from inhaling or ingesting radionuclides. This may occur if they are unaware of airborne contamination and are not wearing protective equipment or if the equipment fails or is used improperly.
14. **Review its capability to measure airborne radioactive contamination.** The ability to measure airborne radioactivity and respond accordingly is essential to an adequate radiation protection program. The lack of exposure information for airborne hazards has proven a problem for veterans of the atmospheric nuclear test program. More recently, potential chemical exposures during the Persian Gulf War at Kamisiyah, Iraq (DoD, 1996; Schaeffer, 1996) have demonstrated how a lack of airborne exposure data creates problems with health assessment activities.
15. **Expand Operational Exposure Guidance to include radiation doses from both internal and external sources of radiation. These should be expressed in terms of effective dose and be consistent with the requirements of the U.S. Nuclear Regulatory Commission**. The lack of consideration of internal dose is a major shortcoming in the ACE Directive.
16 **Adopt the millisievert (mSv) as the standard unit of effective dose and milligray (mGy) as the unit of absorbed dose**. There are three reasons for this recommendation. First, the units currently used in the ACE Directive—centigrays (cGy) and centisieverts (cSv)—are not internationally accepted scientific units. Second, by using millisieverts, all doses to individuals could be compared to one year's nominal U.S. background dose from external sources (1 millisievert). This should make it easier for soldiers to understand their exposures.[3] Third, at low radiation levels, the use of the unit millisievert will reduce, albeit

[3] One millisievert is the average accumulated background radiation dose to an individual for 1 year, exclusive of radon, in the United States.

only slightly, the problems of recording doses that are much less than one and are expressed to several decimal places.

17. **Clearly define the time over which doses are to be accumulated for assignment of radiation exposure status (RES) levels in the Operational Exposure Guidance in Annex A of the Directive.** Presumably, doses are cumulative over a career and are not reset to zero after each operation.
18. **Review and revise doctrine and procedures on dosimetry to ensure individual doses are monitored and recorded for all soldiers exposed to radiation, whether from routine occupational exposure or as a consequence of uniquely military missions.** While the ACE Directive requires that records of individual dose be maintained, existing Army guidance (HQDA, 1994) requires tracking only of unit doses (e.g., average doses for a platoon).

OPERATIONAL EXPOSURE GUIDANCE BELOW 700 MGY

The committee recommends that the Army:

19. **Include radiation doses from internal sources (e.g., from inhaled airborne radioactivity) in applying reference levels in Operational Exposure Guidance.** The reference levels shown in the Operational Exposure Guidance table (Annex A) appear at least as stringent as those found in current civilian radiation protection recommendations of expert national and international advisory bodies. However, the ACE Directive misapplies the levels by assuming there will be no internal doses.
20. **Clearly specify what actions are recommended at each reference level in the Operational Exposure Guidance.** Although the reference levels in the Directive are generally appropriate, the actions recommended at each level lack specificity. Future versions of the Directive or its implementing instructions should specify the details of each action (e.g., when to initiate a monitoring program and what its specific requirements are).
21. **Restructure the table of Operational Exposure Guidance to account for the uncertainty of dose estimates in interventions.** Because of this uncertainty, the two lowest dose categories in the existing guidance are too narrow to be scientifically justified (in the environment of an intervention) and should be combined.
22. **Develop separate Operational Exposure Guidance for managing practices (routine tasks involving radiation exposure) in the context of a military operation.** If the Army adopts the philosophy that soldiers should receive the same level of protection as civilian radiation workers in similar environments and circumstances, the guidance in Annex A should be expanded to include dose limits and reference levels appropriate for a practice as well as an intervention.

CONCLUDING STATEMENT

In summary, the committee views the ACE Directive as a positive step in providing the soldier with protection against the potential adverse effects of ionizing radiation across the spectrum of radiation sources that may be encountered in military operations. In this first part of our study, we have reviewed the adverse effects attributed to radiation exposure and described methods to avoid them. Additionally, we have compared the ACE Directive with prevailing international and national philosophies of radiation protection and the existing Army framework for radiation safety.

We found that the ACE Directive is incomplete in scope and unclear in certain areas. To assist the Army in improving these areas, we have developed several recommendations. Implementation of these should provide the soldier with an acceptable level of protection from adverse effects of radiation, at least from a technical standpoint. In the second part of the study, the committee will consider those factors beyond this technical realm, that is, the ethical, moral, and legal basis for a system of radiation protection applicable to the soldier in the exercise of his or her profession.

1

Introduction

The North Atlantic Treaty Organization (NATO) has recently developed guidelines for limits on and controls for exposure of soldiers to ionizing radiation in the course of military operations (NATO, 1996). This guidance addresses radiation doses ranging from those governed by civilian—public and occupational—guidelines up to the high doses expected during a major nuclear conflict. At the request of the U.S. Army Surgeon General, the Institute of Medicine has convened an expert committee to evaluate these guidelines from scientific and ethical perspectives. This report is Part I of the committee's efforts. It focuses on the scientific merit of this new NATO guidance by responding to the charge:

1. Do the presently proposed NATO guidelines (dose limits, documentation, and control measures) follow generally accepted U.S. national limits and recommended guidelines for radiation protection of occupational and emergency workers?
2. Are these NATO guidelines reasonable from a scientific viewpoint?
3. How could the guidelines be improved?

Next year, the committee will report, in Part II, its follow-on deliberations on other critical factors, including ethics, risk perception, recordkeeping, training, communication, decision making, and additional general scientific information as necessary.

During the Cold War, the United States Army established radiation dose limits and controls for soldiers based on a scenario of global nuclear war (NATO, 1986; HQDA, 1994). Battlefields were expected to be highly contaminated. Radiation dose limits for soldiers were based on criteria that maximized immediate survival and the ability to continue with a combat mission. The upper

bounds of the dose limits were at the threshold for development of radiation sickness.

In the post Cold War setting, military scenarios involving radioactive contamination rarely reflect global nuclear war but more often consider limited nuclear exchanges, terrorist actions using improvised nuclear devices, conventional explosives employed as a means of disseminating radioactive materials, or nuclear power plant accidents. In these scenarios, radioactive contamination would be more restricted geographically, and the immediate risks to a soldier might be much lower. Except in rare circumstances, radiation doses under these scenarios would be well below the lethal level, yet they could be above the occupational dose limits that are applied to civilian workers (CFR, 1991). The new NATO guidance addresses protection for soldiers at risk of exposure at levels that could result in doses above background up to 700 mSv. In this report, the Committee to Study Battlefield Radiation Exposure Criteria reviews this guidance as it is expressed in ACE Directive 80-63 (NATO, 1996).

During the Persian Gulf War, the Army recognized the potential for exposure of soldiers to levels of radiation that exceeded occupational levels but were below levels set in STANAG 2083, *Commanders' Guide on Nuclear Radiation of Groups* (NATO, 1986). During Desert Shield and Storm, the Foreign Science and Technology Center warned of the possibility that conventional explosives could be used by threat forces to disseminate radioactive materials (e.g., from reactor waste or radium and radioactive cesium and cobalt from radiotherapy sources) on the battlefield. The U.S. Army participated in developing NATO radiation protection guidelines for the soldier in the new radiation exposure scenario, with an Army representative heading the NATO team of experts.

Military commanders have always had to weigh multiple risks in their decisions. In the Cold War setting, the emphasis was on acute (immediately life-threatening) risks related to survival. In this new era, commanders face missions, such as peacekeeping and humanitarian assistance, in nonbattlefield environments, in which the risk of immediately disabling and life-threatening injuries is lower.

Thus, the potential for delayed health effects of battlefield activities (e.g., the potential for developing cancer from radiation exposure) takes on new importance. This is new ethical and doctrinal ground for Army planners. They wish to ensure that the standard of protection proposed in the ACE Directive has a sound scientific and ethical basis before they apply it generally in U.S. Army doctrine.

Supreme Headquarters, Allied Powers Europe (SHAPE) recognized a need to plan for potential radiation exposure of military forces in Europe that might occur during the peacekeeping mission to Bosnia. In response, SHAPE staff developed the Allied Command Europe (ACE) Directive Number 80-63, *ACE Policy for Defensive Measures against Low Level Radiological Hazards during Military Operations*.

The Directive applies to all NATO forces in Europe and is intended to provide guidance to military commanders whose troops may encounter radiation

sources. The procedures of the ACE Directive apply to what SHAPE defines as *low-level*[4] *radiation, that is*:

> The doses received from these exposures are higher than those routinely received by health physics [radiation] workers and the general public and are in the range from background radiation to 70 cGy.
> . . . These hazards [exclusive of nuclear weapon detonation] may occur from inadequate nuclear waste disposal, deterioration of nuclear power facilities and damage to institutions that routinely use radioactive material/sources and terrorism. (NATO, 1996, §1-1.a.)

The ACE Directive (see appendix) provides general policy for the conduct of operations in the presence of radiation. It seeks to avoid unnecessary radiation exposure whenever possible and to minimize doses when exposure is unavoidable. In addition, the policy prescribes planning, coordination, security, dosimetry, recordkeeping, training, equipment, and expertise to deal with radiological hazards. Procedures in the Directive outline actions to be taken by responsible commanders in the event of a situation involving radiation exposure. These include methods for assessment of radiation hazard, dissemination of hazard information, and personnel protection. Finally, the Directive includes a chart that defines *radiation exposure status* (RES) categories by which it defines actions to be taken when personnel receive (or are at risk of receiving) specified levels of radiation dose. This chart subdivides dose levels defined in existing guidance (HQDA, 1994; NATO, 1986) as being of *negligible risk* to *moderate risk*.

Radiation is not a new hazard for service personnel. Over 200,000 military personnel participated in U.S. nuclear weapons testing between 1945 and 1962. Five laws have been signed by four presidents in attempts to provide just consideration of claims for compensation for health problems and disabilities these Atomic Veterans attribute to radiation exposure.

The Defense Special Weapons Agency was chartered within the Department of Defense to develop a personnel register and estimate doses for the Atomic Veterans. Thus far, it has been funded in excess of $120 million to execute its continuing mission. Inadequate records for estimating radiation doses received by individuals is one of the most contentious issues surrounding the resolution of these veterans' claims. Accurate primary dosimetry records are unavailable for a great many of the Atomic Veterans. The history of the veterans involved in the above-ground nuclear test program demonstrates clearly the need for detailed and advanced planning for radiation protection, assessment of radiation dose, and development of exposure standards before soldiers are put at risk of exposure. The ACE Directive is a significant step in that direction.

[4] See Chapter 6, Recommendation 4, on terminology in the ACE Directive.

The committee intends (in Part I of this report and Part II to follow) to assist the Army in developing an appropriate radiation protection philosophy and standards over the wide spectrum of radiation exposure situations soldiers may encounter.

2

Principles of Radiation Protection

To understand how to protect soldiers from ionizing radiation,[5] it is necessary to understand its characteristics, how it interacts with tissues in the body, and the effects these interactions may have on immediate and long-term health.

RADIATION PHYSICS

All matter is made up of atoms, each consisting of a nucleus containing neutrons and positively charged protons. Negatively charged electrons surround the nucleus. The nucleus of a radioactive atom has excess energy causing it to be unstable. To become more stable, the radioactive nucleus will eventually release energy in the form of either particulate (e.g., alpha and beta particles) or electromagnetic (e.g., gamma rays) radiation.

When these forms of radiation strike atoms of any material, they may have enough energy to eject electrons. This process, called ionization, can result in the breaking of electron bonds that hold atoms together. Ionization and other radiation-induced effects, such as excitation and free radical formation, cause chemical changes in components of the living cell, including deoxyribonucleic acid (DNA), the genetic material in the cell that is located in the chromosomes within its nucleus.

Alpha particles colliding with atoms give up their energy in a very short distance, such as the thickness of a sheet of paper, less than the thickness of skin, or a few centimeters of air. Consequently, alpha particles are not likely to be

[5] Throughout this report, the term *radiation* refers to ionizing radiation and does not include nonionizing radiation sources, such as lasers and radiofrequency generators.

harmful when striking the outside of a body that is protected by clothing and the outermost dead layer of the skin. However, when these same alpha-emitting radionuclides are taken into the body, they can directly irradiate nearby cells of tissues in which they are deposited and may cause cellular changes. Such changes may result in adverse health effects in the short-or long-term, depending on the nature of the changes. Alpha particles may be encountered in contamination created by intentional or accidental dispersion of nuclear weapon-source materials (e.g., plutonium) or as a result of fallout from a nuclear detonation. Alpha particles from naturally occurring sources of radiation, such as radium and radon, contribute to normal background levels.

Beta particles penetrate to a greater depth than alpha particles before the transfer of all their energy to tissues is complete. However, even high-energy beta particles will give up most of their energy within about one centimeter of plastic, one to two centimeters of tissue, or 4 to 5 meters of air. Therefore, beta particles striking the outside of the body will penetrate only a short distance, but they may travel far enough to damage the actively dividing cells of the skin. Beta particles are of greater concern after they have entered the body and can transfer their energy to nearby cells of internal organs. Beta radiation may be found in contamination consisting of fission products from a nuclear detonation or resulting from dispersion of nuclear reactor waste or radiotherapy sources (e.g., radiocesium and radiocobalt).

Gamma rays and x rays are the most penetrating forms of ionizing radiation and consist of electromagnetic energy. While randomly colliding with electrons in the body, gamma rays may give up all their energy in tissue, or they may pass all the way through the body without interacting. Therefore, exposure to gamma or x rays from sources outside the body may cause ionizations in tissues at any location in their path. Gamma rays are characteristic of a wide variety of radioactive contaminants associated with nuclear weapons and nuclear waste and also with radioactive sources used in medicine and industry, while x rays are most commonly encountered in medical applications (including those in combat medical facilities).

RADIATION UNITS AND MEASUREMENTS

Radiation Units

Exposure

The energy of ionizing radiation is measured and described in a number of ways. One can use a meter or other device to measure exposure—ionization in air caused by radiation. Exposure is measured in coulombs per kilogram (C/kg)

of air, formerly[6] the roentgen (R). This measurement of exposure applies only to ionizing electromagnetic radiation, such as gamma and x rays, not to particulate radiation (e.g., alpha or beta particles). In the field (outside the laboratory), *exposure* is the quantity that is measured, although for convenience, it is commonly assumed that exposure and absorbed dose (see below) are the same when expressed in traditional units (i.e., 1 R = 1 rad).

While beta and alpha radiations can be detected in the field, determination of their contribution to tissue dose is a complex process not reasonably implemented except under laboratory conditions. Exposure to alpha-and beta-emitting radionuclides is expressed as the concentration of these radionuclides in air, food, and water. The primary dose to persons exposed to these concentrations results from ingestion and inhalation of the radionuclides.

Absorbed Dose

A useful quantity in radiation physics is the energy actually deposited in a certain amount (mass) of tissue. This unit is referred to as absorbed dose. The unit of *absorbed dose* is the gray (Gy), formerly the rad. One Gy equals 100 rad; 1 milligray (mGy) equals 100 millirad (mrad). However, the amount of energy deposited in tissue does not account for differences in biologic effects of different radiation types.

Equivalent Dose

The dosimetric quantity that accounts for the differences in biologic effectiveness of various types of radiation and allows doses from different radiations to be combined is called the *equivalent dose*. It is calculated by multiplying the absorbed dose by the appropriate radiation weighting factor, "WR" (ICRP, 1991a). For example, the factor for alpha particles is 20 and that for gamma and beta radiation is 1, indicating that it takes about 20 times more gamma or beta radiation than alpha radiation to cause a given effect. The unit of equivalent dose is the sievert, formerly the rem. One sievert (Sv) equals 100 rem; 1 millisievert (mSv) equals 100 millirem (mrem).

Effective Dose

Just as different radiation types have greater or lesser effectiveness in damaging tissue, different tissues types have varying sensitivity to that damage. For a

[6] Common usage before the 1960 Conference Generale des Poids et Measures at which the International System of Units (SI) was adopted.

given dose of radiation, highly sensitive tissues show a greater increase in cancer rate than do less sensitive tissues. For radiation protection purposes ICRP has developed weighting factors for tissues (called "W_T") that describe the sensitivity of different tissues. Tissue weighting factors facilitate combining doses to allow quantitative comparison of long-term risk from partial body exposure to that from total body exposure. From that combination of doses one can estimate the risk of radiation effects for the entire body. Tissues that are very sensitive to long-term effects from radiation have high weighting factors (e.g., bone marrow $W_T = 0.12$), while less sensitive tissues have lower weighting factors (e.g., skin $W_T = 0.01$).

The effective dose to the whole body is found by multiplying the equivalent dose in each tissue type by its corresponding tissue weighting factor and adding the results for each tissue type. This composite dose is proportional to the increased risk from cancer and genetic effects. Like the equivalent dose, the effective dose is expressed in units of sieverts (Sv) or millisieverts (mSv). Dose limits set for occupational exposures are expressed as effective dose and include both internal and external doses. Table 2-1 compares the characteristics of the three ways in which dose in biological tissue may be expressed.

Table 2-1. Comparison of Three Expressions of Dose in Biological Tissue

	Correction Applied	International Unit	Traditional[a] Unit
Absorbed dose	No correction	Gy or mGy	rad or mrad
Equivalent dose	Correction of absorbed dose for effectiveness of the radiation type (alpha, beta, gamma, etc.) using W_R[b]	Sv or mSv	rem or mrem
Effective dose	Same correction as equivalent dose and correction for sensitivity of tissues using W_T[c]	Sv or mSv	rem or mrem

[a] 1 Gy = 100 rad and 1 Sv = 100 rem.
[b] WR is the ICRP radiation weighting factor.
[c] WT is the ICRP tissue weighting factor (ICRP, 1991a).

Radiation Measurement

It is critical that radiation measurement equipment be suited to its measurement task. Important considerations are the accuracy and sensitivity of the instrument chosen. Alpha, beta, and gamma (or x-ray) radiation measurements each require different instruments because of the way in which each radiation type interacts with matter. An instrument designed for alpha detection, for ex

ample, will not give accurate information for the other types of radiation. A radiation safety program specifies the appropriate equipment to be used in estimating exposure to an individual from external radiation sources.

For directly measuring individual doses of gamma radiation (and, under some conditions, beta radiation), a thermoluminescent dosimeter (TLD) is often used. The TLD will give a reasonable measure of the dose to the whole body from gamma rays from a broadly distributed source. Because of the short range of beta particles, however, a TLD will only indicate the dose received from this type of radiation in its immediate location.

Doses to individuals may also be calculated indirectly if exposure rates are known from radiation surveys (radiation measurements made in the field). Two types of radiation survey instruments are helpful for assessing the potential for exposure to military personnel in the field. The first type measures the radiation exposure or dose to which personnel may be subjected. This category of instrument includes devices such as microroentgen meters and ion chambers. The second type of meter is represented by Geiger-Mueller or sodium-iodide detectors. These meters are used for finding contamination, although the Geiger-Mueller detector may be calibrated to provide exposure readings.

An ion chamber is designed to measure exposure, that is, ionization in air due to gamma rays (in C/kg or R). This instrument measures the quantity of radiation energy at a point in the air. Ion chambers normally come equipped with a moveable cover over the detection chamber. When the cover is open, the instrument will respond to alpha and beta particles, as well as gamma rays. However, these instruments are not usually calibrated for alpha and beta particles, so the instrument reading may not be accurate for them.

A Geiger-Mueller detector is primarily designed to measure the number of alpha, beta, or gamma rays emanating from a source and striking the detector in a given time. This meter does not normally provide information about the energy of incident radiation or about exposure. However, it can be calibrated to relate the number of gamma rays to a known ionization in air to give readings in units of C/kg (or roentgen).

The devices discussed briefly above are useful for detecting or measuring contamination on surfaces (e.g., on the ground or on a vehicle such as a tank), but they cannot directly detect low levels of airborne radioactivity that might be hazardous. To determine whether airborne contamination is a health problem, an additional device—the air sampler—is required. This device removes radioactive contamination from the air and concentrates it sufficiently to be measurable by a detector similar to those discussed above.

Determining dose for internal exposures from inhaled or ingested radionuclides is much more difficult and time-consuming than determining external dose. It requires measurements of air (or water or food) contamination, identification of significant radionuclides, measurement of amounts excreted, and the application of sophisticated biomathematical models to determine doses to specific organs. Gamma-emitting radionuclides deposited in the body can be detected and measured with instruments external to the body. Under battlefield

conditions, rough measurements of environmental contamination can be made as a basis for estimating dose. If calibration factors are available for open window ion chambers and GM counters, those instruments may be used to get a very crude estimate of airborne contamination. Under less adverse conditions, more sophisticated instrumentation and techniques should be applied.

SOURCES OF RADIATION EXPOSURE

In this section we provide a perspective for the radiation doses soldiers could receive in the course of military operations. Under normal conditions, everyone is exposed to background ionizing radiation from two major sources: continuous, naturally occurring radiation from space and from radioactive elements and technology-enhanced (often referred to as manmade) radiation sources. Natural sources of radiation constitute the major source of radiation exposure to the populations of most, if not all, countries, with the next largest source being applications of medical technology.

In the United States the average annual effective dose of naturally occurring background radiation is about 3 mSv (0.30 rem) per year (NCRP, 1987). Of this, about 2 mSv (0.20 rem) come from exposure to radon, 0.28 mSv (0.028 rem) from cosmic rays, 0.39 mSv (0.039 rem) from naturally occurring radionuclides in the human body, and finally, 0.28 mSv (0.028 rem) comes from naturally occurring radioactive materials within the ground (terrestrial). The effective dose from all natural sources during a 70-year lifetime is approximately 200 mSv (20 rem). Levels of background radiation vary significantly across geographic areas. In the United States, for example, the natural background radiation from cosmic rays and terrestrial sources in Denver, Colorado, is 50 percent higher (NCRP, 1987) than the national average. Thus a resident of Denver receives about 0.3 mSv [0.03 rem] per year more than the average resident of the United States.

In addition to the doses of background radiation received annually, some soldiers are engaged in duties in which they are at risk of exposure to higher levels of ionizing radiation. Examples of such duties include repairing and maintaining radioactive commodities (such as depleted uranium ammunition and luminescent sights containing tritium), flying at high altitudes, and administering medical diagnostic and therapy procedures. Table 2-2 shows the distribution of occupational doses for Army radiation workers.

Apart from routine occupational exposures, the only exposure of large numbers of U.S. military personnel to radiation has been to those who were in the occupation forces near Nagasaki and Hiroshima, Japan at the close of World War II and to those who participated in the above-ground nuclear test program conducted between 1945 and 1962. Of these 210,000 military personnel, about 1,200 received doses that were estimated to exceed 50 mSv (5 rem) (DSWA, 1995a)—the present annual dose limit set by the U.S. Nuclear Regulatory Commission (CFR, 1991) for individuals occupationally at risk of exposure to radiation. About 20,000 participants (DSWA, 1995b) have been assigned esti

mated doses that exceed the more conservative annual occupational limit—20 mSv (2 rem)—recommended by the ICRP (1991a). A total of 0.07 percent of the doses exceeded 100 mSv (10 rem), and the average estimated dose for an Atomic Veteran is 6 mSv (0.6 rem).

Table 2-2. Distribution of Annual Doses (1996) for Army Personnel (Military and Civilian) Monitored for Occupational Exposure to Radiationa

Dose Range (mSv)	No. in Dose Range	Percentage of Total
0	13,187	82.7
0–1	2,461	5.4
1–5	269	1.7
5–10	17	0.1
10–50	2	0.0
50–100	1	0.0
>100	2	0.0
Total	15,939	99.9[b]

[a] Compiled from radiation monitoring records maintained by the U.S. Army Ionizing Radiation Dosimetry Center (USAIRDC) at Redstone Arsenal, Alabama.
[b] Does not total 100 percent due to rounding.

RADIATION BIOLOGY

The most critical target of ionizing radiations passing through living tissues is generally accepted to be the DNA that constitutes the genes in the nucleus of every cell. Ionizing radiation can damage DNA directly or indirectly. For direct damage to occur, the radiation must hit this genetic material. Since the volume of the DNA is very small compared with the total volume of the cell, the probability of this occurring is low. Indirect damage occurs when radiation interacts in close proximity to the genetic material—the interaction can create a free radical in water that can subsequently damage DNA. Two-thirds of the tissue damage created by radiation is caused by these indirect processes.

Complete and accurate biological repair of such DNA damage is a normal process that occurs millions of times daily. However, under certain conditions, radiation-induced DNA damage can be irreparable, or the repair can be incomplete or inaccurate. This can result in the appearance of acute adverse health effects (within about 2 months) or delayed effects (over many years, even decades after the exposure).

Most radiation at environmental levels (background) does not result in detectable health effects. The reason is that most radiation interactions occur in the water in the cells of the body, producing free radicals that rapidly dissipate without doing biological damage.

Generally, when radioactive contaminants enter the body, the radionuclides are not uniformly distributed. As a result the dose may be highly localized. Uniform irradiation of the entire (whole) body, by radionuclides deposited inside it,

is very rare and occurs only with very soluble, usually beta-or gamma-emitting, radionuclides. Animal studies have demonstrated that nonuniform distribution of energy through tissues, such as from radioactive particles, is less hazardous than uniform distribution because of the lower number of cells at risk (EPA, 1976; Nenot and Stather, 1979). Cancers resulting from intake of radionuclides are more likely to arise in those tissues that contain the highest concentrations of radionuclides. Some tissues, such as lymph nodes, are much less susceptible to radiation-caused cancers than others, such as red bone marrow.

For a tissue to be affected by radiation it must be directly irradiated. For example, radiation to the hand from an x-ray machine cannot cause primary health effects in other parts of the body. Most acute effects of radiation are due to cell killing and are deterministic in nature. Long-term effects are usually due to mutations and are termed stochastic effects.

Deterministic Effects

Irreparable radiation-induced DNA damage results in premature cell death or inability of the cell to divide. If cells are damaged faster than they can be replaced or repaired, health may be adversely affected. If this damage-vs.-repair differential is present, clinical signs will be detectable and symptoms may develop early in the postexposure period (within about 2 months).

The type and severity of deterministic effects depend upon the type of ionizing radiation involved, the magnitude of the dose, and the rate at which the dose is accumulated (dose rate). As described above, gamma and x-ray radiations emitted by sources outside the body can penetrate several tens of centimeters of tissue to interact with DNA in cells deep within the body. High-energy beta emitters on or close to the skin can penetrate the skin's outer layer of dead and aging cells to reach the actively dividing cells beneath. These exposures have the potential to cause local skin injuries and effects within the range of the radiation. Such manifestations of acute radiation-induced health effects can occur alone, in combination with each other, and with nonradiation-induced trauma, including thermal burns, or other serious medical conditions. Combined injuries of these types tend to have a greater effect on the health of the exposed person than the sum of the effects of the individual injuries.

Accidents involving humans, medical experience, and animal studies indicate that doses of radiation must exceed a threshold in order to cause the various types of acute health effects (injuries) that have been described. Thresholds for several radiation effects of interest are shown in Table 2-3.

If the dose is accumulated instantaneously or within a short time, the threshold doses for early radiation effects may be quickly reached or exceeded, resulting in acute effects. This can occur in the event of a high dose from a source outside the body (e.g., nuclear weapon detonation) at a high dose rate. If, however, the same total dose is accumulated over a longer period of time (i.e., is fractionated or protracted), the types of deterministic health effects due to the exposure are likely to be fewer in number and less severe. The effects of pro

tracted or fractionated doses are less than acute doses because the numbers of cells being killed by the radiation over time will be less than the number of new cells being produced in the body's tissue systems during the same period and because repair of radiation injury occurs within most cells. Distribution of doses over long time periods can occur with external exposures and when long-lived radionuclides are deposited inside the body. The likelihood of alpha and beta emitters deposited inside the body causing generalized symptoms of radiation exposure early in the postexposure period is minimized by their limited penetrating power, which restricts their biological effectiveness to nearby cells.

Table 2-3. Estimated Threshold Doses for Deterministic Effects of Acute Radiation Exposure

Health Effect	Organ	Dose (mSv)	Reference
Temporary sterility	Testis	150	ICRP, 1984
Depression of blood-cell forming process	Bone marrow	500	ICRP, 1984
Reversible skin effects (e.g., reddening)	Skin	1,000–2,000	UNSCEAR, 1982
Permanent sterility	Ovaries	2,500–6,000	ICRP, 1984
Temporary hair loss	Skin	3,000–5,000	UNSCEAR, 1982
Permanent sterility	Testis	3,500	ICRP, 1984
Cataract	Lens of the eye	5,000	ICRP, 1984

Another key factor in the body's response to ionizing radiation is the relative sensitivity to radiation of the various cell types that comprise body tissues. Bergonié and Tribondeau's Law (1906) implies that rapidly dividing cells (e.g., cells of the blood forming tissues and certain groups of immature sperm cells) are among the most sensitive to acute effects of radiation. The more highly differentiated cells (e.g., muscle and nerve cells) are less vulnerable to acute injury by radiation. Other factors that influence the expression of the deterministic effects of radiation include the region of the body irradiated and variation between individuals in their physiologic response to radiation.

A small group of deterministic effects tends to appear beyond the characteristic early (2 month) postexposure period. This group reflects irreparable DNA damage incurred at the time of exposure and subsequent cell death. It includes cataracts, infertility in males and females, suppression of thyroid gland function, and fibroatrophy as a consequence of radiation-induced damage to connective tissue and blood vessels. These effects are associated with practical threshold doses that are typically higher than those of concern in this report.

Of special concern in the modern military would be the radiation-induced damage that could occur in the embryo or fetus as the result of the inadvertent exposure to radiation of a pregnant soldier. A dose of greater than 50 mSv (5 rem) to the embryo or fetus is associated with an increase in risk (relative to the nonexposed) of nonspecific deterministic effects in the forms of embryonic

death, congenital malformations, or mental and growth retardation, depending on the period of gestation during which the exposure occurred (Brent, 1989).

Stochastic Effects

Incomplete repair, or misrepair, of radiation-induced DNA damage increases the risk of tumors and hereditary effects that may appear many years later, unless the damage is inconsistent with cell survival and division. Such damaging effects occur randomly among individuals in exposed populations or their offspring. The frequency and probability of their occurrence, but not their severity, increase with increasing radiation dose. The type of late effects that can occur depends on the type of cells affected.

Radiation-induced gene mutations in some types of cells (somatic) can result in abnormal cell growth that may be benign (noncancerous) or malignant (cancerous). In theory, these abnormal growths can be initiated in a single irradiated (and transformed) cell, but a variety of biological factors protect against every transformed cell progressing to become a malignant focus for cancer or leukemia development. Such factors include the age of the individual at exposure, gender, genetic heritage, and the immune system's ability to resist cancer. Theoretically, and for radiation protection purposes, it is assumed that there is no dose below which the probability of such effects occurring is zero, that is, there are no threshold doses for radiation-induced tumors.

It takes time for damage to DNA to result in a radiation-induced tumor. The interval between the exposure and the detection or diagnosis of a tumor attributable to the exposure is termed the latent period. The latent period is generally accepted to be a minimum of 2–5 years for radiation-induced leukemias and 10 years for most solid cancers.

While all cell types are assumed to be susceptible to malignant transformation by ionizing radiation, cells in certain tissues appear to be more susceptible. Increased risks of benign (noncancerous) nodules in thyroid gland and female breast tissue, several types of cancer (e.g., lung, thyroid gland, and female breast), and all forms of leukemia except chronic lymphocytic leukemia have been strongly associated with external exposure to ionizing radiations, primarily at high dose rates. Examples of populations in which these associations have been found include the Japanese atomic bomb survivors, some groups who had medical diagnostic or treatment exposure, and some occupationally exposed individuals.

In the atomic bomb survivor population, statistically significant associations between increases in death rates for certain cancers and leukemia and radiation dose have been reported among groups who received doses of 200 mSv (20 rem) or more (Shimizu et al., 1990). A recent update of cancer mortality among the same population suggests an increased risk for cancer mortality at a lower level—above doses of 50 mSv (5 rem) (Pierce et al., 1996).

Increased risks of death due to cancers of certain organs and other malignant tumors related to exposure to radiation from radionuclides deposited in suscep

tible tissues have been reported among females occupationally exposed to radium and patients treated with radium. Thyroid cancers have occurred in persons exposed to radioactive iodines in radioactive fallout and lung cancers have been observed in uranium and other miners exposed (by inhalation) to the radioactive decay products of naturally occurring radon underground (NRC, 1988). Several of these populations were exposed to high levels of radiation for long periods of time.

The lifetime risk of fatal cancers associated with exposure to low doses of radiation (100 mSv [10 rem]) at low dose rates is estimated to be a factor of 2 to 4 less than the risk associated with exposure to higher doses and dose rates (NRC, 1990).

Studies of cancer mortality among radiation workers whose exposures were controlled by stringent radiation protection standards (i.e., at low doses and low dose rates) yield risk estimates consistent with those derived for low doses and low dose rates from studies of cancer mortality among atomic bomb survivors (Cardis et al., 1995). Several studies of the mortality experience of American and British Atomic Veterans (e.g., Johnson et al., 1996; Darby et al., 1988, 1993a, 1993b; Watanabe et al., 1995) have been completed, but they have not provided convincing evidence of detrimental radiation effects on long-term survival.

Gene mutations in reproductive cells (sperm or ova) can increase the risk of stochastic effects in the form of nonspecific heritable genetic diseases among the offspring of irradiated organisms. Experimental animal and plant studies show that the probability of such effects occurring is related to radiation dose. However, no increased risk (compared to nonexposed populations) of such diseases has been documented among the children of atomic bomb survivors who were exposed before conceiving their children (NRC, 1991).

Recently, there was considerable interest in determining whether the Atomic Veterans and their families may have experienced adverse reproductive outcomes (e.g., stillbirths, infertility, birth defects, etc.) as a result of their exposure to radiation. The Institute of Medicine considered the feasibility of such a study and reported as follows (IOM, 1995):

> The committee's assessment is that there are insurmountable difficulties in finding, and contacting a sufficiently large number of study subjects (offspring of the Atomic Veterans), in establishing an accurate measure of dose for each veteran, in detecting the extremely small potential risk at low doses, in identifying and reliably documenting reproductive outcomes over a 50-year interval, and in the measuring of other factors that have been observed to cause reproductive problems, and therefore, might confound any observed relationship between radiation exposure and reproductive problems. These difficulties become even greater in the grandchildren of these veterans. The committee concluded, therefore, that as a result of the difficulties enumerated above, the cohort of Atomic Veterans does not provide a practical opportunity for a scientifically adequate and epidemiologically valid study.

RADIATION DOSE REDUCTION

There are three primary means of reducing radiation dose from sources external to the body: *time, distance,* and *shielding*.

For a given source of radiation, the amount of radiation energy deposited in the body is related to how long one is exposed. Therefore, reducing the duration of an individual's exposure to radiation will decrease dose.

Increasing the distance between an individual and a radiation source is an important means of reducing radiation exposure, because the intensity of the radiation is inversely proportional to the square of the distance from the radiation source. For example, when the distance from a localized source is doubled, the intensity of the radiation is reduced by a factor of 4 (22).

Shielding is useful for absorbing radiation energy. If enough interactions occur in the shielding material, then much of the radiation is prevented from reaching the body's tissues. Alpha particles can be stopped by a piece of paper. Beta particles are blocked by about a centimeter of plastic. Clothing and the outer layers of skin cells provide some protection from beta particles outside the body. Gamma rays, however, may require many centimeters of lead or meters of concrete for shielding.

Once a radioactive material is taken into the body, the protective measures of distance and shielding cannot be applied. However, the duration of internal exposure may be reduced by increasing the rate of excretion of the radioactive material through elimination of body fluids or solids. The primary means of protection from internal radiation exposure is to prevent radioactive materials from entering the body in the first place. Appropriate respiratory protection can prevent the inhalation of airborne radioactive materials. Ingestion is prevented by not eating, drinking, or smoking where radioactive materials are present.

3

Standard Practices in Civilian Radiation Protection

To determine whether the NATO guidance embodied in the ACE Directive adequately follows generally accepted practices of radiation protection, we must first review standard practice. At the foundation of any system is an underlying philosophy, however implicit it may be. The international basis of radiation protection practice has been developed explicitly by the International Commission on Radiological Protection (ICRP). This has been considered and adapted for use in the United States by the National Council on Radiation Protection and Measurements (NCRP). Based on their own needs and the recommendations of these bodies, various U.S. federal agencies, such as the Nuclear Regulatory Commission and the Environmental Protection Agency, develop specific implementing regulations.

In this section we summarize the current radiation protection philosophy in the United States. We will then use this as a yardstick against which to compare the ACE Directive.

CONTROL PHILOSOPHY

The philosophy of radiation protection has to include social as well as scientific judgments in order to provide an appropriate standard of protection without unduly limiting practices. The overall aim of radiation protection, regardless of the specifics of the situation leading to exposure, is to prevent the occurrence of acute effects (e.g., cataracts in the eyes, radiation bums, and acute radiation sickness) and ensure that all reasonable steps are taken to reduce the potential long-term effects, such as cancer (ICRP, 1991a), to a level that is acceptable to

society. The methods applied to achieve that aim will vary, depending upon the radiation exposure scenario. The two types that we will address are

- practices (routine and potential), and
- interventions.

The first of these, the *practice*, is an intentional activity in which the practitioner is routinely at risk of exposure. Workers who are exposed to radiation during the course of their duties include, for example, x-ray technicians in hospitals, nuclear power plant workers, and researchers who use radioactive materials. The practices in which they engage include taking x rays of patients, running a nuclear reactor, or making measurements using radioactive sources. These occupationally exposed individuals are trained to appreciate the hazards of radiation, acknowledge those risks as a condition of employment, and follow safety precautions in order to minimize their exposure.

Any practice may have exposures that do not routinely occur (such as accidents). If these have not yet happened, they are called *potential exposures*. Both the probability of such events happening and the magnitude of expected radiation doses can be calculated in planning responses. These also should be considered in the introduction and management of new practices. If an accident actually happens, *interventions* are taken to reduce exposure.

An *intervention* is an action that one takes to reduce a radiation exposure (often to other individuals or groups) from specific radiation sources by (ICRP, 1993):

- reducing or removing the existing sources,
- improving the reliability of the existing sources,
- modifying pathways,[7] or
- reducing the number of exposed individuals.

An example of an intervention would be the response of the firefighters who fought to control the fire in the Chernobyl nuclear reactor accident. Often an intervention is associated with an emergency action.

To distinguish practice from intervention, it is helpful to consider that prior to the accident, the Chernobyl workers were engaged in a practice—production of electric power for the Ukraine. The workers in the plant were operating under a radiation protection program required for a practice, which included management's option of discontinuing or changing the practice to eliminate or reduce radiation exposure. The firefighters who responded after the accident were operating under different rules and exposure criteria—those intended for an intervention situation.

[7] Pathways are the routes by which radiation gets to the exposed individual (e.g., contaminated foodstuffs or radionuclides carried by the wind).

In both practices and interventions, one applies three basic principles:

- justification,
- optimization/ALARA,[8] and
- limits or reference levels.

Radiation exposure is generally considered as something to be avoided, at least unless there is a good reason that justifies it. As mentioned in the introduction, effects of radiation at low doses (less than 50 mSv) have not been observed in humans. However, because of the uncertainty surrounding low-dose effects, most radiation protection philosophy presumes that even small radiation doses may produce some deleterious effects. For that reason, the first principle of radiation protection is *justification:* All practices that involve exposure should produce a benefit that outweighs the potential harm from radiation (ICRP, 1991a).

As an example of justification, consider the use of medical x rays. Technicians may receive small doses of radiation and potentially some harm, but the greater good provided to patients by the diagnostic x ray is enormous, hence the practice is justified. Justification is essential in developing radiation protection for practices and interventions and also will be applied in planning for potential exposures.

Once an activity involving exposure has been justified, one must then Minimize the exposure that will result from that action. *Optimization* is the word used by ICRP to describe that minimization process. An activity is optimized when the resulting dose is reduced to a level that is "as low as is reasonably achievable (ALARA), economic and social factors having been taken into account" (ICRP, 1991a).

Finally, even when a practice is justified and has been optimized, there are *limits* above which people should not routinely be exposed. Dose limits, when observed, prevent individuals from acquiring doses that are clearly unacceptable. This could happen in a poorly controlled occupational situation involving radiation. Dose limits apply only to practices.

For interventions—where the primary goal is to accomplish the emergency action—dose limits are not used. Neither are dose limits applicable in planning for potential exposures. When the potential is realized—such as in an accident—the response is often an intervention rather than a practice. In the case of a postaccident intervention, application of an occupational dose limit could prevent emergency workers from performing critical actions necessary to limit great harm to a large population. Dose limits do not apply to (or include) natural

[8] ALARA is an acronym that conveys the principle that "In relation to any particular source within a practice, the magnitude of individual doses, the number of people exposed, and the likelihood of incurring [radiation] exposures where these are not certain to be received should all be kept as low *as reasonably achievable,* economic and social factors being taken into account" (ICRP, 1991a, para 112(b)).

background radiation. Nor do they apply to patients undergoing medical procedures that involve radiation exposure.

Thus far, we have discussed radiation protection principles without regard to the population that is being protected. Although the principles apply to anyone, the implementation depends on the circumstances under which one is exposed. Workers who are exposed to radiation as a consequence of their employment choose to accept that exposure and the practice of protection as conditions of employment. Members of the general public may also be exposed to radiation sources (e.g., while waiting in a radiology clinic or a cancer therapy department). Unlike occupational workers, however, the general public does not receive direct compensation in return for their exposure, nor do they formally accept the risk of exposure. Because of that, limits for exposures are lower for these groups. Occupational doses are currently limited (CFR, 1991) to 50 mSv per year, whereas exposures to the general public are limited to one fiftieth of that—1 mSv per year (approximately the same as the annual background dose from sources excluding radon) (NCRP, 1987). While both these limits apply to both males and females, more stringent limits (5 mSv, which is 10 times lower than the usual worker limit) apply to a fetus during gestation.[9] By contrast, dose limit guidance for an adult acting to save valuable property during an emergency is set much higher (100 mSv, EPA, 1991).

Dose limits can easily be misinterpreted. They are not intended as demarcations of safety—keeping doses below the limits does not guarantee the absence of increased cancer risk. Dose limits represent, for a defined set of practices, a level of dose above which the consequences for the individual would be widely regarded as unacceptable (ICRP, 1991a). In the current system of radiation protection in the U.S. (CFR, 1991), a continuous annual dose to a worker above the annual limit (50 mSv) is considered unacceptable.

Intervening to limit damage after a nuclear accident (urgent action) presents its own set of problems (ICRP, 1991b). People who are in the immediate vicinity may be exposed to radiation levels that can only be estimated after the incident. Those who respond to the situation (firefighters and other emergency workers) may be exposed to doses in excess of the annual U.S. occupational limit of 50 mSv in trying to protect valuable equipment, save lives, or prevent radiation exposure of large populations. In this scenario, the principles of justification and optimization continue to apply. However, since worker exposures may be unpredictable, unknown, and difficult to control in the earliest stages of an accident, dose limits are inappropriate. Nevertheless, ICRP recommends that, where possible, the effective dose to individuals be kept below 1,000 mSv to limit deterministic effects. Where possible, except to save a life, dose to the skin should be limited to 5,000 mSv. Also, intervention levels for sheltering and evacuation,

[9] This exposure limit applies only to the fetus of pregnant women who have acknowledged (declared) their pregnancy to their employer. See reference CFR, 1991.

contamination levels for foodstuffs, and procedures for thyroid protection have been recommended by the ICRP (1991b) and the EPA (1991).

After the urgent action phase of an accident, additional personnel may assist with evacuation of the local population, provide emergency medical care, or provide security around the accident site. During that phase, justification and at least crude optimization are applied (ICRP, 1991b). The ICRP also recommends that doses be kept within occupational limits, if possible.

Finally, once the accident is under control, a recovery period begins, during which the hazard at the site is brought under permanent control. Since this may take an extended period of time, during which the urgency of the situation is diminished, conventional occupational radiation protection controls are appropriate.

In summary, radiation protection is based on justification, optimization, and, in the case of routine practices, dose limits. However, it would be terribly inefficient to go through the justification and optimization processes every time a recurring situation arose. For many recurring situations, it may be possible to go through these processes once and define what actions should be taken in response to a set of similar circumstances when a particular level of exposure or dose is exceeded. The resulting *reference levels* (ICRP, 1991a) take into account justification, optimization, and dose limits in directing radiation protection policy changes, administrative responses, or other actions.

Reference levels are fundamentally different from dose limits. Whereas dose limits specify (usually with regulatory authority) a dose level that should not be exceeded during routine operations, reference levels give guidance that certain decisions should be made or certain actions should be taken if or when the level is exceeded.

A variety of organizations have recommended dose limits and reference levels (Table 3-1). These are applicable to a number of different populations in a variety of exposure scenarios. The table is by no means an inclusive list but provides comparisons that put radiation exposure into perspective.

In addition to the underlying philosophy, radiation protection programs include provisions for actions such as monitoring compliance, recordkeeping, training, health surveillance, and defining the responsibilities of management and governmental authorities.

Table 3-1. Examples of Typical Radiation Doses and Dose Limits or Reference Levels (mSv)

Description of level	Effective Dose (mSv)	Reference
Annual background dose to a person living in the United States, excluding radon	1	NCRP, 1987
Typical effective dose from a CT scan	1	NCRP, 1987
Annual limit on exposure of members of the general public	1	ICRP, 1991a
One-year continuous exposure at the edge of the "Radiological Hazard Area" as defined by ACE Directive 80-63	20	NATO, 1996
Annual dose limit for radiation workers (averaged over a 5-year period)	20	ICRP, 1991a
Lifetime increase in background dose from living in Denver vs. national average	20	IOM, 1995
Limit for emergency services, except lifesaving, protection of valuable property, or protection of large populations	50	EPA, 1991
Annual dose limit for radiation workers	50	CFR,1991
Total background radiation, excluding radon, over a 70-year lifespan	70	NCRP, 1987
Limit for protecting valuable property	100	EPA, 1991
Total background radiation, including radon, over a 70-year lifespan	210	NCRP, 1987
Limit for saving a life	250	EPA, 1991
Limit for volunteers saving a life	>250	EPA, 1991
Threshold for deterministic effects[a] (e.g., bone marrow depression)	500	ICRP, 1984
Career dose limit for radiation workers	1,000	ICRP, 1991a
Astronaut career cumulative dose (female, career beginning at age 25)	1,000	NCRP, 1989
Astronaut career cumulative dose (male, career beginning at age 25)	1,500	NCRP, 1989
NATO Emergency Risk for disaster situations	1,500	HQDA, 1994
Lethal dose (50% mortality in 60 days without treatment)	3,000	Schull, 1995

[a] That is, not cancer or hereditary effects.

NOTIFICATION, TRAINING, AND INFORMED UNDERSTANDING

Training is an essential part of all radiation protection programs (NCRP, 1983). It is the mechanism by which those at risk are notified of the likelihood of exposure to radiation and the accompanying risk of adverse effects. Training provides the knowledge by which those at risk can minimize their dose and, therefore, the potential adverse effects on their health. A clear understanding of the risk from radiation in comparison to other competing hazards allows one to weigh various risks to make better informed decisions. A cavalier attitude toward radiation can lead to actions that yield unnecessarily high exposures. Likewise, excessive fear of radiation can produce decisions that trigger more severe risks and consequences than the radiation itself would have occasioned.

The degree of training required for an individual depends upon the likelihood and extent of the radiation hazard to which that person may be exposed. For example, annual instruction in radiation safety may be considered sufficient for radiological technicians in a clinical environment as part of a program to keep their doses as low as reasonably achievable. By contrast, workers at a nuclear power plant receive detailed training on radiation exposure reduction techniques every time they conduct special operations in a high radiation area.

RECORDKEEPING

Recordkeeping is another essential element of a radiation protection program (ICRP, 1991a). Maintaining records (NCRP, 1992) on exposure serves to:

- aid in protection of individuals;
- evaluate the effectiveness of radiation protection programs;
- provide for accuracy, reliability, confidentiality, and retrievability of data;
- provide evidence of regulatory compliance;
- provide data for epidemiologic studies; and
- provide information for making or contesting claims for radiation-induced injury.

Among the records commonly kept on radiation exposures are the following:

Program documents record any authorizations and accreditations that allow or regulate the exposure of individuals to radiation (e.g., radioactive material licenses from the USNRC or DoD authorizations to possess radioactive commodities). They also include all documentation necessary to define the radiation protection program that safeguards the health and well-being of workers. Among these records one would find records of training programs, dosimetry procedures, environmental monitoring plans, documentation of efforts to keep exposures ALARA, and so on.

Individual records document relevant data on each individual exposed to radiation as part of occupational duties. These include items such as exposure

categories for individuals (e.g., managers who get minimal radiation doses vs. technicians who get larger doses). Also of interest are individual dose records (internal and external), training records, and details of any overexposures, as well as age, gender, and other identification data that allow individuals to be followed in epidemiologic studies. Records should follow the individual as he or she changes employer or work situation. It also is useful to record individual work history and conditions; that allows calculation of accumulated internal dose after an exposure occurs.

Workplace records document activities and conditions in the environs of the individual exposures. These records include data on radiation levels in various areas, descriptions of restricted areas, descriptions of activities that require personnel exposures (work permits), records of movements of radioactive materials, data on protective equipment availability and condition, and documentation of accidents and incidents.

Environmental records document radiologically significant characteristics of the environment to include results of measurements of radionuclide content of the air, ground, and water. These records can be valuable in reconstructing doses to personnel who may have been exposed during a release of radioactivity.

Instrumentation records are maintained to document the availability, calibration, maintenance, and capability of radiation detection and measurement devices. These are used for quality control purposes to ensure the accuracy of radiological measurements.

4

Current Paradigms for Radiation Protection in the Army

The Army has two separate programs to control radiation exposure to soldiers. One is applied to those individuals whose duties parallel those of civilian radiation workers. These include military personnel such as x-ray technicians, radiologists who do radiological examinations, researchers using radioisotopes, and technicians who maintain radioactive commodities such as Geiger counter calibration sources. The Army's other radiation protection program is intended to apply only during situations of extremely high radiation exposure, such as nuclear war.

OCCUPATIONAL EXPOSURE

In peacetime, soldiers who are considered to be at risk of exposure to radiation in the execution of their duties are safeguarded by radiation protection regulations (DoDI, 1996) that are comparable to those of their civilian counterparts. The radiation limits prescribed by these regulations (see examples in Table 2-3) are derived from U.S. Nuclear Regulatory Commission (USNRC) standards, which for the most part[10] reflect recommendations of the ICRP and NCRP.

Radioactive commodities in the Army are controlled, as they are in civilian industrial operations, under licenses issued by the USNRC. Exposures that could result from the fabrication, maintenance, or application of these radioactive commodities are subject to control under civilian regulations (CFR, 1991) that

[10] There are significant differences between ICRP and NCRP and NRC in the values of W_R, some dose limits, and in some other areas.

tend to implement the general philosophy and practices espoused by the ICRP and NCRP.

Army-specific requirements for control and safe handling of radioactive commodities are under the jurisdiction of the Army Materiel Command (AMC, 1980), while the protection of individual soldiers is a medical function under the purview of the Office of the Surgeon General (OTSG, 1995a, 1995b). Two OTSG medical documents constitute the bulk of the individual radiation protection program in the Army. Although the regulations provide a measure of radiation protection to soldiers that parallels that of civilians in similar environments and circumstances, they do not extend that same protection in militarily unique missions, as the following excerpt from Army (Medical) Regulation 40-14 demonstrates:

> **Applicability.** This regulation applies to Department of the Army (DA) and Defense Logistics Agency (DLA) installations and activities. This includes the Army National Guard of the United States (ARNGUS), U.S. Army Reserve (USAR), and civilians under contract with the DA or DLA who perform tasks involving occupational exposure to DA and DLA controlled radioactive material or radiation-producing devices. *This publication is not applicable during mobilization or anytime the U.S. Army adopts a state of readiness directly preparatory to actual or imminent armed conflict in a geographical zone where peacetime occupational radiation exposure conditions cannot reasonably be construed to prevail*.

a. In particular, this regulation remains applicable to DA and DLA personnel deployed on either humanitarian or peacekeeping missions where the degree of readiness to respond to hostile fire requires the availability of radioactive commodities, such as depleted uranium ammunition, as a contingency.
b. *This regulation does NOT apply to the following:*

(1) Personnel exposed to ionizing radiation and radioactive materials resulting from the use of ionizing radiation sources and devices in geographical areas or zones where—

(a) *Hostile fire or combat already exists or is strongly anticipated to occur, or*
(b) *Combat missions are intentionally going to be conducted by Department of Defense personnel*.

(2) Patients exposed to ionizing radiation in the course of medical and dental examination, diagnosis, or treatment. This exception does not apply to health care providers.
(3) Human research subjects exposed to ionizing radiation in the course of voluntary participation in medical research programs.
(4) Doses received from natural background radiation.

[Emphasis added.]

HIGH-LEVEL EXPOSURES IN NUCLEAR WAR

Exposure to radiation anticipated during times of war has been assumed to be the result of nuclear weapon detonation. Training soldiers to operate in a nuclear environment has been conducted since the advent of nuclear weapons and continues to this day (HQDA, 1983, 1992, 1993). Radiation protection practice under these conditions has been driven by the need for soldiers to survive to accomplish their immediate mission. In this scenario, the risk of stochastic effects, including cancer, has been a secondary concern.

NATO Standardization Agreement 2083 (NATO, 1986) defines exposure criteria for use in planning for the commitment of troops to a radiologically contaminated area that would result in high-level exposures to radiation. These criteria are implemented in the U.S. Army by Field Manual 3-3-1 (HQDA, 1994). Their purpose is to control the cumulative radiation dose received by combat units. One of four radiation exposure status categories (Table 4-1) is assigned to a unit, depending on its cumulative dose. The unit dose is an average of the doses to individuals in the unit who have dosimeters. Protocol requires that during operations in a nuclear environment, individual dosimeters be read daily and the results passed up the chain of command. Records of summary exposure data are maintained at battalion level for subordinate company and platoon-sized units and are then forwarded to higher commands, which keep more broadly aggregated records.

Currently, the Army does not record doses on *individual* soldiers who are exposed to battlefield radiation. Doctrine requires that 2 soldiers per squad (about 25 percent) have self-reading dosimeters; there are usually 3 squads in a platoon. Until it implements individual dosimetry, the Army assumes that each soldier gets an individual dose equal to that of the average for the platoon (HQDA, 1994). The Army plans to equip each soldier, eventually, with a dosimeter, but the type expected to be deployed (DT-236) will be useful for recording, doses only in excess of about 100 mSv.

Since the platoon is the lowest aggregate level for which records are kept, replacements for exposed units are made at the platoon level. When a soldier leaves an exposed unit, the radiation exposure status (RES) for that platoon (not the soldier's individual dose) is noted in the soldier's personnel file. Where possible, soldiers are reassigned to platoons with the same RES category, which, although creating severe management problems, is intended to keep personnel from incapacitation due to overexposure to radiation.

TABLE 4-1. Nuclear Radiation Exposure Status and Degree of Risk Exposure

Radiation Status Category [a,b]	Total Past Cumulative Dose[c] (cGy)	Possible exposure criteria for a single operation that will not result in exceeding the dose criteria for the stated degree of risk[d,e] (cGy)
RES-0	No exposure	Negligible risk: ≤ 50 [500 mGy] Moderate risk: ≤ 70 [700 mGy] Emergency risk: ≤ 150 [1500 mGy]
RES-1	More than 0, but less than or equal to 70 [700 mGy]	Negligible risk: ≤ 10 [100 mGy] Moderate risk: ≤ 30 [300 mGy] Emergency risk: ≤ 110 [1100 mGy]
RES-2	More than 70 [700 mGy], but less than or equal to 150 [1500 mGy]	Any further exposure is considered to exceed a negligible or moderate risk. Emergency risk: ≤ 40 [400 mGy]
RES-3	More than 150 [1500 mGy]	Any further exposure will exceed the emergency risk.

[a]Radiation status categories are based on previous exposure to radiation.
[b]Reclassification of units from one radiation status category to a less serious one is made by the commander, upon advice of the surgeon, after ample observation of actual state of health of exposed personnel.
[c]All exposures to radiation are considered total body and simply additive. No allowance is made for body recovery from radiation injury.
[d]Risk levels are graduated within each status category to provide more stringent criteria as the total radiation dose accumulated becomes more serious. The exposure criteria given for RES-1 and RES-2 units should be used only when the numerical value of a unit's total past cumulative dose is unknown.
[e]Each of the degrees of risk can be applied to radiation hazards resulting from enemy or friendly weapons, or both, and from initial nuclear radiation resulting from planned friendly supporting fire.

SOURCE: HQDA. Nuclear Contamination Avoidance, Field Manual 3-3-1. Washington, D.C.: Headquarters, Department of the Army, 1994.

SUMMARY OF EXISTING ARMY PROGRAMS

The discussion thus far demonstrates a wide gap in the Arm's radiation protection program. The occupational radiation protection program limits exposures to 50 mSv annually. The Army's Operational Exposure Guidance (Table 4-1) considers exposures a factor of 10 higher than that (500 mGy) to be in the negligible risk category. Therefore, for situations for which there is potential for exposures between 50 and 500 mGy, there exists a range of doses for which there is no guidance. It was to fill that gap that the NATO team of experts proposed Table 4-2 below.

This table was integrated into ACE Directive 80-63 as guidance for radiation protection to the troops assigned to the peacekeeping mission to Bosnia. The next section describes that document, which appears in its entirety in the Appendix.

Table 4-2. Operational Exposure Guidance for Low-Level Radiation

Total Cumulative Dose (cGy)[a,b,c]	RES Category	State[d,e]	Actions
< 0.05 cGy [0.5 mGy]	0	No risk	• None
0.05 to 0.5 cGy [0.5–5 mGy]	1A	Normal risk	• Record individual dose readings and • Initiate periodic monitoring
0.5 to 5 cGy [5–50 mGy]	1B	Minimal risk	• Record individual dose readings and continue monitoring • Initiate rad survey • Prioritize tasks • Establish dose control measures as part of operations
5 to 10 cGy [50–100 mGy]	1C	Limited risk	• Record individual dose readings • Continue monitoring and update survey • Continue dose control measures • Execute priority tasks only (see Note f)
10 to 25 cGy [100–250 mGy] See Note g	1D	Increased risk	• Record individual dose readings • Continue monitoring and update survey • Continue dose control measures • Execute critical tasks only (see Note g)
25 to 70 cGy [250–700 mGy] See Note h	1E	Significant risk	• Record individual dose readings • Continue monitoring and update survey • Continue dose control measures • Execute critical tasks only

Total Cumulative Dose (cGy)[a,b,c]	RES Category	State[d,e]	Actions

[a] Dose is uniform to the entire body due to whole body irradiation. This table does not consider the intake of radioactive material. This is assumed due to employment of effective respiratory protection and other measures.

[b] All doses should be kept as low as reasonably achievable (ALARA). This will reduce individual soldier risk as well as retain maximum operational flexibility for future employment of exposed soldiers.

[c] The use of the measurement millisieverts (mSv) is preferred in all cases. However, due to the fact that normally the military has only the capability to measure Centigray (cGy), as long as the ability to obtain measurements in mSv is not possible, ACE forces will use cGy. For whole body Gamma irradiation: 1 cGy = 10 mSv.

[d] Risk is of long-term health consequences primarily induction of fatal cancer starting two years postexposure. Total lifetime risk is assumed to be four to seven percent per 100 cGy (= 1000 mSv). This is in addition to the 20–25% incidence of fatal cancer among the general-population. Additional health risks that may occur are teratogenesis and mutagenesis and their associated psychological and social consequences.

[e] It must be noted that higher radiation dose rates produce proportionally more other health risk than the same total dose given over a longer period.

[f] Examples of priority tasks are those missions to avert danger to persons or to prevent damage from spreading. Examples of critical tasks are those missions to save human lives.

[g] During peacetime this dose shall not be exceeded except to save human lives.

[h] RES category 1E covers a wide range of dose and its lower level (25 cGy = 250 mSv) is the peacetime maximum operational dose in many NATO nations. This category is normally only applicable in wartime. Intentional exposures to doses in this category (25–70 cGy = 250–700 mSv) require additional justification.

SOURCE: NATO. ACE policy for defensive measures against low-level radiological hazards during military operations. ACE Directive Number 80-69. Brussels, Belgium: SHAPE (Supreme Headquarters Allied Powers Europe), 2 August 1996.

5

Evaluation of the ACE Directive in Light of Civilian Standard Practices

The previous sections describe the potential adverse health consequences of radiation exposure and outline the currently accepted methods for limiting those consequences. In light of that background, we will now consider how well the ACE Directive fulfills a similar mission specifically for soldiers.

The Army has published guidance for control of doses from routine occupational exposures and those associated with nuclear war. The ACE Directive is an encouraging step in developing control measures for other situations. We realize that the Directive was meant for a specific mission (Bosnia) and that the Army recognizes its limitations. The criticisms that follow should be viewed as constructive and in no way diminish the significant progress that the Army has made toward the control of the complete spectrum of radiation hazards on the battlefield and in operational situations other than war.

In this review we will look first at general characteristics of the ACE Directive as compared to existing radiation protection methods in the civilian sector. Then we will make several comments on specific parts of the Directive.

UNDERLYING PHILOSOPHY OF RADIATION PROTECTION

We begin with an assessment of the underlying philosophy of the ACE Directive. The Directive states (NATO, 1996, § 1-2.) that:

a. Deliberate exposure of ACE Forces to a radiological hazard shall not be permitted unless it is required by military necessity.
b. All exposures of soldiers to radiological hazards during operations must be kept as low as reasonably achievable consistent with military necessity.

From that standpoint, the Directive captures the two central principles of radiation protection as they apply to interventions. These are justification and optimization. The Directive does not appear to use the concept of practices, for which there are specified dose limits, since none are mentioned in the Directive policy statement.

Several dose and dose rate levels in the Directive are associated with actions of one type or another. For example, a survey team is directed to turn back when one of its members encounters a dose rate of 0.003 mGy/hr (0.0003 rad/hr), and commanders are to establish dose control measures as part of operations at a cumulative dose of 5–50 mGy (0.5–5 rad) (NATO, 1996). These may be thought of as reference levels—values at which certain actions should occur.[11] Although it does not specifically say so, the ACE Directive assumes an underlying philosophy that corresponds closely to that of an intervention as defined by ICRP.

The analogy of military action as intervention is not perfect. ICRP sees an intervention as an action directed at the radiation source, e.g., to prevent further contamination or to put out a fire in a reactor. In the case of the Army, the object of the intervention may have nothing to do with the radiation source.

Many situations in military operations resemble practices more than interventions. For example, sending a survey team into an area of unknown radioactive contamination is clearly an intervention, and the ACE Directive is applicable. On the other hand, consider a soldier assigned to guard the entrance of a damaged nuclear plant. The dose rate at the guard station probably would have been measured as the result of a preceding intervention. Providing routine guard services would no longer be part of the intervention. At that point, exposure levels should be well known and dose to the soldier should therefore be kept not only as low as reasonably achievable but also within accepted dose limits. This activity should be controlled as a practice, not as an intervention.

Having said that, we hasten to say that a military operation is a unique situation where simple definitions of practices and interventions become complex and conditions may change quickly. In the civilian version of our scenario, the guard would finish a shift and go home. In the military situation, the plant may suddenly come under attack, resulting in the guard being unable to avoid exceeding occupational limits. Thus, the military situation that began as a practice, subject to dose limits, must now be managed as an intervention.

One could argue that all military operations, since they involve such uncertain situations, should be managed as interventions, without dose limits. However, given the substantial involvement of the military in peacekeeping and humanitarian assistance missions, it is hard to justify not providing soldiers with the level of protection that controlling exposures as a practice would provide.

[11] The only place we encounter defined exposure limits in the ACE Directive is in setting maximum exposure guidance prior to a mission (ACE Directive para. 1-3.f.(2)). This is much like ICRP's recommendation that doses greater than about 500 mSv not be permitted except to save a life (ICRP, 60, 6.3.2[225]).

For nonemergency situations, the ACE Directive does not provide guidance that would afford protection to soldiers at a level appropriate for a practice.

TERMINOLOGY

There are terms in the ACE Directive that the committee considers misleading. The first, and by far the most serious issue, is the term *Low Level Radiation* when it is applied broadly to doses in the range 50 to 700 mSv (5 to 70 rem). *Low level* may be an appropriate descriptor when comparing these doses to those that could result from the detonation of a nuclear device. In the broader context of radiation protection, however, *low level* clearly implies much lower doses. While the terminology may be perfectly clear to those involved in developing the guidance, it probably will be misunderstood by others. The Army's use of this term to describe doses that approach thresholds for acute effects easily could be misinterpreted as an intent to mislead soldiers on the seriousness of such exposures.

The committee has concerns about the terms used to describe effects of dose categories in the table in Annex A. *No risk* is used to describe the effect of doses less than 0.5 mGy (0.05 rad). This is inconsistent with international positions on the effects of radiation, specifically the assumption that even small radiation doses may produce some deleterious effects. Likewise, the term *normal risk* incorrectly implies that an exposure of 0.5 to 5 mGy (0.05 to 0.5 rad) adds no additional risk to that from natural background radiation exposure, even though such exposures are considered to contribute very small, possibly negligible, health risks.

Radiological hazard is often used in the ACE Directive to describe any radiation exposure.[12] Hazard is an ambiguous term. Given the uncertainty as to the magnitude of the health consequences at low levels, the term *hazard* should not be appended to *radiation* automatically. Rather, it should be used advisedly to identify the potential for significant health consequences.

PROSPECTIVE RISK ASSESSMENT

The ACE Directive (NATO, 1996, § 1-3.a. and c.(1)) indicates that there is a prospective assessment of risk, high or low. It is unclear whether this refers to (a) intelligence assessments of the *likelihood* of radiation contamination or (b) the magnitude of measurable *levels* of radiation contamination.

In principle, the committee agrees with the Directive's requirement for "dose rate instruments to measure alpha-and beta-emitting particles as well as gamma radiations" (§1-3.b.). Instruments sensitive to beta and alpha radiation will be useful in conducting assessments for potential skin contamination and

[12] See for example ACE Directive § 1-2.a.

internal deposition and for triggering appropriate protective actions. However, the exact wording of the requirement suggests that the instrumentation will be capable of measuring "dose rate." The committee is not aware of any instruments that can directly measure beta and alpha radiation dose rates in the field.

DEFINITION OF A RADIOLOGICAL AREA

The ACE Directive defines a radiological hazard area as anywhere the dose rate is in excess of 0.002 mGy/hr (0.0002 rad/hr). This dose rate is approximately 20 times the background radiation dose rate found in the United States (NCRP, 1987) and one-tenth the maximum dose rate allowed for uncontrolled areas that members of the public might frequent. If a soldier were to spend a year in such an area—0.002 mGy/hr (0.0002 rad/hr)—a worst case scenario, that soldier would accrue a dose of approximately 20 mGy (2 rad). That is equal to the ICRP recommended annual dose limit for civilian radiation workers. Continuous exposure at this level would not exceed the current U.S. radiation worker annual exposure limit of 50 mSv set by the Nuclear Regulatory Commission (CFR, 1991). Given its consistency with these comparison figures, the radiation dose rate at the edge of the exclusion zone is reasonable for defining contaminated areas and instituting radiation protection actions.

DOSIMETRY REQUIREMENTS

The ACE Directive requires that, in deciding to allow a soldier to be put at risk of exposure to radiation, a commander will ensure that an accurate radiation dose is recorded to document that soldier's exposure (NATO, 1996). To do that, the commander must be able to determine an accurate dose for each individual soldier. The committee agrees with that requirement but finds its implementation problematic.

Available dosimeters may not be capable of providing adequate dosimetry. The IM-93 pocket dosimeter, currently fielded for individual soldiers, is not issued to all and is fragile and prone to error in rugged field use. The dosimeter planned for individual issue, the DT-236, is not sensitive below 100 mGy (10 rad). Thus, it cannot be used to differentiate between exposures in the low dose categories specified in the ACE Directive. Thermoluminescent dosimeters that can be used to monitor dose at low dose levels are available from the Army Dosimetry Center, but the equipment needed to read these devices is not normally available or issued to combat units. In summary, although individual dosimetry is appropriately required by the Directive, it may be difficult to do with currently available hardware.

The level of exposure at which dosimetry is recommended is stated in the Operational Exposure Guidance table of the ACE Directive. At 0.5 mSv (0.05 rad), the beginning of RES category labeled "1A," the commander is advised to

record individual dose readings, and initiate periodic monitoring." It is not clear what circumstances would lead to the start of individual dosimetry. If individual dosimetry has not yet begun, how is it determined that the 0.5 mSv (0.05 rem) level has been exceeded, triggering the start of periodic monitoring? We assume that there are no dose histories, since monitoring has not yet begun. Therefore, the decision to start monitoring must be based upon *projected* whole body doses of 0.5 mSv or more. Similarly, in civilian practice, the decision to issue individual dosimeters for monitoring can be made based on projected doses. However, the ACE Directive requirement is considerably more stringent than that commonly followed in occupational programs and the rest of the DoD (DoDI, 1996). The DoD requires monitoring of individual doses only above 5 mSv (0.5 rem), ten times the ACE Directive recommended level.

There is an inconsistency between the text (NATO, 1996, § 1-3.f.(3.)) and the table in Annex A. The text states that:

> Commanders must ensure that once a decision to allow exposure to *any* radiation is made, radiation dose management systems are initiated in accordance with national regulations. The commander shall ensure that the dose a soldier receives is accurately recorded upon each radiological exposure and that the total dose is annotated in his individual national medical record in accordance with national regulations. [Emphasis added.]

The table of Annex A, however, directs that monitoring begin at 0.5 mGy (0.05 rad). As a result of this ambiguity, it is conceivable that an individual could enter a low level contaminated zone without dosimetry. It is possible that this could result in exposure from unknown, localized hot spots that could cause doses above the monitoring threshold in Annex A.

DOSE UNITS

While it is understandable that the radiation community within the military might want to retain the familiar unit of absorbed dose, the *rad*, and rename it the centigray, *cGy*, the practice is not internationally accepted. The same may be said for the unit of effective dose, the *cSv*, as a pseudonym for the *rem*.

Reported doses and particularly dose rates will probably be low. Reporting doses and survey measurements in cGy, or cGy/hr, will require the use of very small decimal numbers (e.g., the ACE Directive limit on a contaminated area of "0.0002 cGy/hr"). In handwritten transmissions of data, this could lead to errors in transcription (e.g., 0.0002 mistaken for 0.00002).

INTERNAL DOSE

While the ACE Directive requires individual assignment of external whole body doses, there do not appear to be any requirements to identify or evaluate

internal deposition of radionuclides or to estimate the radiation dose from such depositions. Neither is there a requirement to determine the potential for internal dose hazards in the area of operations. In fact, Note 1 of the table in Annex A to the Directive (NATO, 1996) states that:

> Dose is uniform to the entire body due to whole body irradiation. This table does not consider the intake of radioactive material. This is assumed due to employment of effective respiratory protection and other measures.

The ACE Directive recognizes the problem of internalized radioactive materials—soldiers are directed to put on their protective masks when in a radiological hazard area (NATO, 1996)—but proceeds under the assumption that no such exposures will occur. The ACE Directive assumes that the respiratory protection is 100 percent effective and is silent on situations in which protective equipment is not worn or is defective. The ACE Directive does not specify, quantitatively, at what level of radiological contamination the protective mask should be worn.

The note in the table cited above implies that protective clothing and respirators are being used whenever *any* radioactivity above background is detected. ACE Directive paragraph 1-3.g.(1) requires that respiratory protection be worn in a "radiological area," but the area is not defined (§1-3.c.(2)(c)) by airborne radioactive contamination levels. It is conceivable that the wearing of the protective mask could be required when the actual air concentration is well within acceptable limits. This could happen if the radiological contamination was not easily resuspended or was fixed on the surfaces of military hardware that had been partially decontaminated. On a very hot day, the wearing of the protective mask under these conditions would unnecessarily diminish the performance of the soldier, perhaps increasing risk of other nonradiation hazards, jeopardizing the mission.

DOSE CUMULATION TIMES

In addition to knowing the total dose accumulated by an individual, it is useful to know the time history of that exposure. The ACE Directive enhancements to the Operational Exposure Guidance specify that dose reference levels are to be used with cumulative doses. However, the guidance does not specify whether doses are accumulated over an operation, a year, or a lifetime. It does not appear that individual dose records indicating prior occupational and other exposures will be available to commanders in assigning RES categories.

REFERENCE LEVELS FOR OPERATIONAL EXPOSURE GUIDANCE

The ACE Directive Operational Exposure Guidance table (Annex A) subdivides the some-exposure category (RES-1, our Table 4-1) of existing OEG guidance (HQDA, 1994, NATO, 1986). Each level is accompanied by a narra

tive description of the risk corresponding to a dose level and by a series of required control actions.

The appropriateness of the dose categories depends largely on the way in which they will be used. These categories could be very useful and appropriate in controlling individual exposures and making future assignments. Such uses assume that individual dosimetry is available with the resolution and sensitivity of better than 0.5 mGy (0.05 rad, the width of the narrowest category). Without that, it will be impossible to resolve exposures into the lower RES categories.

If the table is intended for planning interventions in heavily contaminated areas, the fine detail in the lower categories may not be useful. It is not uncommon in nuclear accident areas (e.g., Chernobyl) to find wide variation in dose rates across small distances. Individuals could easily stray into hot spots where dose rates are significantly higher (e.g., by a factor of 10) than initial survey estimates would indicate. Without real-time, self-reading,[13] individual dosimetry, it would be unreasonable to expect to control doses for all individuals in the first two RES categories (0–0.5 mGy [0–0.05 rem] and 0.5–5 mGy [0.05–0.5 rem]).

There is no indication in the ACE Directive of how unknown doses will be handled in recording individual doses or in assigning RES categories to units. In occupational radiation protection practice, it is normal to assign an administrative dose or to estimate a dose based upon best available data.

At doses ranging, from 5 to 50 mGy (0.5–5 rad, RES Category 1B), the Operational Exposure Guidance recommends "establishing dose control measures as part of operations." If we consider that the dose limit for the public used by the USNRC until 1994 was 5 mSv, this level for beginning dose control might be appropriate. However, the current limit for public exposure is 1 mSv (ICRP, 1991a; CFR, 1991). In addition, the ACE Directive itself institutes controls of radiation exposure beginning at 0.002 mGy/hr (0.0002 rad/hr). From this it would appear that some measures of control may be appropriate below the Category 1B level.

Radiation exposure status category IC indicates that only priority tasks are to be attempted between 50 mGy (5 rad) and 100 mGy (10 rad). Priority tasks are defined as those to avert danger to persons or to prevent damage from spreading. This level is comparable to EPA (1991) guidance that allows up to 100 mSv (10 rem) for similar tasks.[14] It is also within the 500-mSv limit recommended by NCRP (1993). In the next higher exposure categories—1D (100–250 mSv, 10–25 rad) and 1E (250–700 mSv, 25–70 rad)—the ACE Directive limits missions to those that are necessary to save a life. The only difference between these two categories appears to be that the lower band is described as *increased*

[13] Some dosimeters like the IM-92 can be read by the soldier himself, at any time, enabling him to control his dose during the mission. Other dosimeters (e.g., the DT-236) can only be read by special equipment not available to the individual soldier during a mission.

[14] For comparisons in this paragraph we are assuming that the exposure is to gamma or x-ray radiation and that 1 mGy ≈ 1 mSv (1 rad ≈ 1 rem).

risk and the higher as *significant risk*. The actions associated with them are the same. In emergencies, ICRP (1991b) recommends that every effort be made to keep doses below 1,000 mSv (100 rem) to prevent serious deterministic health effects (e.g., acute radiation sickness). The exposure levels in 1D and 1E are in keeping with that guidance.

RECORDKEEPING REQUIREMENTS

The ACE Directive (§1-3.f.(3)) requires preparation and maintenance of individual medical records. Again, implementation is in question. Current Army doctrine for maintaining records during *combat* operations (HQDA, 1994) specifies that only the unit's radiation exposure status is transferred with the individual soldier. On the other hand, the Department of Defense requires that during *peacetime* individual doses be maintained (DoDI, 1996).

The ACE Directive (§1-3.f.(3)) requires commanders to ensure that the dose a soldier receives is accurately recorded upon each radiological exposure and that the total dose is annotated in his or her individual medical record in accordance with national regulations. Also, the theater commander (§1-3.f.(4)) is charged with ensuring "that the appropriate medical and NBC Cells [consisting of specialists in nuclear, biological, and chemical matters] are tasked to receive, monitor and maintain all radiological data in accordance with *national regulations* [emphasis added]." For U.S. soldiers, it is not clear whether that means in accordance with Nuclear Regulatory Commission guidelines or Army regulations. The committee assumes that this refers to the Nuclear Regulatory Commission regulations. If that is the case, then internal doses must be documented along with external doses.

The ACE Directive does not specify exactly what dose-related data must be collected (e.g., internal dose, external dose, effective dose, environmental data, etc.). Ultimately, it may be necessary to link this information from its repository to an individual for purposes of compensation determinations or epidemiologic study.

6

Recommendations for Revisions of the ACE Directive

While the ACE Directive is a commendable initial effort to establish guidelines to protect soldiers in the field from the adverse effects of radiation, the committee recommends that it be revised to assure completeness and clarity.

The Army requested that the committee complete its technical review of the ACE Directive as quickly as possible, concentrating on the broader issues of ethics and law, risk perception, training, recordkeeping, and communication in the second year of the study. The technical recommendations we now present do not yet include these extremely important considerations.

Not surprisingly, however, we found each technical point to be associated with numerous considerations that involve societal, organizational, and personal values. The committee will spend its next year of research and deliberation in providing the Office of the Army Surgeon General with cogent and practical guidance that includes and reflects this broader philosophical context. Because of this, the evaluation of the ACE Directive is a work in progress and will not be complete until the final report adds the broader perspective.

UNDERLYING PHILOSOPHY

The committee recommends that the Army:

1. **Provide soldiers the same level of radiation protection as civilians working in similar environments**. The ACE Directive appears to manage all military missions involving radiation exposures as interventions. While this is clearly appropriate for many missions (e.g., emergencies, radiation accidents, and operations involving hostile action), other missions can more properly be

treated as routine practices, thereby affording more complete control of the radiation exposure. Missions amenable to control as practices might include security details, decontamination of vehicles, and other scenarios in which hostile action is not expected.

2. **Develop and state an explicit radiation protection philosophy that defines missions as falling under the framework of either a practice or an intervention**. *Practices* would be subject to modified requirements of the Army's existing occupational radiation protection program as previously described. It is likely that the situation in Bosnia would fall into this category. Under the committee's recommendations, soldiers would be considered radiation workers if they are assigned military duties that have the potential for radiation exposures that could result in doses in excess of the International Commission on Radiological Protection limits for the public (ICRP, 1991a)—1 mSv per year. A revision of the existing exposure guidance in the ACE Directive would govern those situations that are of an emergency nature and would be managed as *interventions*. In both cases, keeping doses as low as reasonably achievable will continue to be of primary importance.
3. **Clearly state in the policy paragraph of the subsequent versions of the ACE Directive the definitions adopted for practices and interventions in the necessary military context.** The procedures that follow the policy statement should address practice and intervention separately. It would seem reasonable for the commander to have the authority to determine which of these frameworks to follow based upon the military mission.

TERMINOLOGY IN THE ACE DIRECTIVE

The committee recommends that the Army:

4. **Not use the term *low level* to describe the radiation dose range of 50–700 milligray (mGy) (5–70 rad).** *Low level* may be an appropriate descriptor when comparing these doses to those that may be experienced from the detonation of a nuclear weapon. In the broader context of radiation protection, however, *low level* clearly implies much lower doses.
5. **Use terms other than *no risk* and *normal risk* for the risk state categories labeled RES 0 and RES 1A in the table of exposure guidance in Annex A of the ACE Directive.** To describe any nonzero dose as *no risk* is inconsistent with current international positions on the effects of radiation. Likewise, the term *normal risk* incorrectly implies *no* additional risk to that from natural background radiation exposures, even though such exposures are considered to contribute very small, possibly negligible, health risks.
6. **Avoid the term *radiological hazard* when describing the exposure of soldiers to radiation, unless the hazard refers to a specific detrimental effect**. For most cases in the ACE Directive *radiological hazard* simply means *radiation*.

PROSPECTIVE RISK ASSESSMENTS

The committee recommends that the Army:

7. **Develop requirements for measuring, interpreting, and responding to airborne and surface contamination (particularly that containing alpha and beta emitters). Guidance should define levels of alpha and beta contamination that would trigger use of protective equipment and actions.** The ACE Directive gives only cursory consideration to this topic and the terminology used to describe the instrumentation necessary for the detection and measurement of radioactive contamination is not clear.
8. **Reconsider its absolute requirement that soldiers wear protective equipment within an exclusion zone as defined in the ACE Directive** . The decision to use protective equipment should be based on the potential for personal contamination with radioactive materials, externally or internally. To require respiratory protection regardless of the existence of an airborne hazard may be counterproductive to completing the mission in a timely and effective manner.
9. **Make a clear distinction between military intelligence threat estimates and radiation risk estimates.** It is unclear, in the *Intelligence* procedures section (NATO, 1996, §1-3.a.), whether *risk (high or low)* refers to (a) intelligence assessments of the *likelihood* of radiation contamination or (b) the magnitude of measurable *levels* of radiation contamination.
10. **Develop explicit requirements to define when individual radiation monitoring is required in the field.** The guidance on whether a soldier could enter a low-level contaminated area without individual dose monitoring is vague. It would be reasonable to require individual dosimetry for all incursions into an exclusion zone where radioactive contamination is likely.

DOSIMETRY REQUIREMENTS

The committee recommends that the Army:

11. **Review its dosimetry capabilities and determine if they are adequate to support the use of the Operational Exposure Guidance in the ACE Directive.** In order to manage soldier exposures according to the ACE Directive, all soldiers would have to have dosimeters that can measure doses as low as 0.5 mGy (0.05 rad).
12. **Increase specificity of the dosimetry program guidelines in subsequent versions of the Directive (e.g., provide specific guidance on the capabilities of monitoring devices and equipment).** The committee considers radiological monitoring and dose estimation for individuals, outside the occupational environment, as areas that require significant attention by the Army.
13. **Not assume, as the ACE Directive does, that internal doses will be zero because respiratory protection will be used**. Soldiers may receive an

internal dose from inhaling or ingesting radionuclides. This may occur if they are unaware of airborne contamination and are not wearing protective equipment or if the equipment fails or is used improperly.

14. **Review its capability to measure airborne radioactive contamination.** The ability to measure airborne radioactivity and respond accordingly is essential to an adequate radiation protection program. The lack of exposure information for airborne hazards has proven a problem, as noted previously for the Atomic Veterans. More recently, potential chemical exposures during the Persian Gulf War at Kamisiyah, Iraq (DoD, 1996; Schaeffer, 1996) have demonstrated how a lack of airborne exposure data creates problems with health assessment activities.
15. **Expand Operational Exposure Guidance to include radiation doses from both internal and external sources of radiation. These should be expressed in terms of effective dose and be consistent with the requirements of the U.S. Nuclear Regulatory Commission**. The lack of consideration of internal dose is a major shortcoming in the ACE Directive.
16. **Adopt the millisievert (mSv) as the standard unit of effective dose and milligray (mGy) as the unit of absorbed dose**. There are three reasons for this recommendation. First, the units currently used in the ACE Directive—centigrays (cGy) and centisieverts (cSv)—are not internationally accepted scientific units. Second, by using millisieverts, all doses to individuals can be compared to one year's nominal U.S. background dose from external sources (1 mSv). This should make it easier for soldiers to understand their exposures.[15] Third, at low radiation levels, the use of the unit millisievert will reduce, albeit only slightly, the problems of recording doses that are much less than one and are expressed to several decimal places (e.g., 0.00002).
17. **Clearly define the time over which doses are to be accumulated for assignment of radiation exposure status (RES) levels in the Operational Exposure Guidance in Annex A of the Directive.** Presumably, doses are cumulative over a career and are not reset to zero after each operation.
18. **Review and revise doctrine and procedures on dosimetry to ensure individual doses are monitored and recorded for all soldiers exposed to radiation, whether from routine occupational exposure or as a consequence of uniquely military missions.** While the ACE Directive requires that records of individual dose be maintained, existing guidance (HQDA, 1994) requires tracking only of unit doses (e.g., average doses for a platoon).

15 One millisievert is the average accumulated background radiation dose to an individual for 1 year, exclusive of radon, in the United States.

OPERATIONAL EXPOSURE GUIDANCE BELOW 700 MGY

The committee recommends that the Army:

19. **Include radiation doses from internal sources (e.g., from inhaled airborne radioactivity) in applying reference levels in Operational Exposure Guidance.** The reference levels shown in the Operational Exposure Guidance table (Annex A) appear at least as stringent as those found in current civilian radiation protection recommendations of expert national and international advisory bodies. However, the ACE Directive misapplies the levels by assuming there will be no internal doses.
20. **Clearly specify what actions are recommended at each reference level in the Operational Exposure Guidance.** Although the reference levels in the Directive are generally appropriate, the actions recommended at each level lack specificity. Future versions of the Directive or its implementing instructions should specify the details of each action (e.g., when to initiate a monitoring program and what its specific requirements are).
21. **Restructure the table of Operational Exposure Guidance to account for the uncertainty of dose estimates in interventions.** Because of this uncertainty, the two lowest dose categories in the existing guidance are too narrow to be scientifically justified (in the environment of an intervention) and should be combined.
22. **Develop separate Operational Exposure Guidance for managing practices (routine tasks involving radiation exposure) in the context of a military operation.** If the Army adopts the philosophy that soldiers should receive the same level of protection as civilian radiation workers in similar environments and circumstances, the guidance in Annex A should be expanded to include dose limits and reference levels appropriate for a practice as well as an intervention.

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Conclusion

In summary, the committee views the ACE Directive as a positive step in providing the soldier with protection against the potential adverse effects of ionizing radiation across the spectrum of radiation sources that may be encountered in military operations. In this first part of our study, we have reviewed the adverse effects attributed to radiation exposure and described methods to avoid them. Additionally, we have compared the ACE Directive with prevailing international and national philosophies of radiation protection and the existing Army framework for radiation safety.

We found that the ACE Directive is incomplete in scope and unclear in certain areas. To assist the Army in improving these areas, we have developed several recommendations. Implementation of these should provide the soldier with an acceptable level of protection from adverse effects of radiation, at least from a technical standpoint. In the second part of the study, the committee will consider those factors beyond this technical realm, that is, the ethical, moral, and legal basis for a system of radiation protection applicable to the soldier in the exercise of his or her profession.

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Appendix

The ACE Directive

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SUPREME HEADQUARTERS
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B - 7010 SHAPE BELGIUM

GRAND QUARTIER GENERAL
DES PUISSANCES ALLIEES
EN EUROPE
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ACE DIRECTIVE
NUMBER 80-63

02 AUG 1996

ACE Policy for Defensive Measures against
Low Level Radiological Hazards during Military Operations

This directive supersedes Allied Command Europe (ACE) Directive 80-63, dated 10 January 1996. ACE Directive 00-1, "Index to ACE Directive and Manuals" is to be amended to indicate the current date of this directive..

REFERENCES:

A. ACE Directive 75-3 - NBC Defence Organization, Equipment and Training for ACE Headquarters and Formations under OPCON of SACEUR
B. ACE Directive 80-14 - Nuclear, Biological and Chemical Defence Equipment Operational Guidelines
C. STANAG 2002 - Warning Signs for the Marking of Contaminated or Dangerous Land Areas, Complete Equipments, Supplies and Stores
D. STANAG 2083 - Commanders Guide on Nuclear Radiation Exposure of Groups
E. STANAG 2103 -reporting Nuclear Detonations, Biological and Chemical Attacks, and Predicting the Warning of Associated Hazards and Hazard Areas (Allied Tactical Publication 45 (A))
F. STANAG 2112 - NBC Reconnaissance
G. STANAG 2150 - Standards of Proficiency for NBC Defence
H. STANAG 2352 - NBC Defence Equipment Operational Guidelines

1. Applicability. This directive is applicable to all ACE International Headquarters and formations under operational control of SACEUR.

2. Supplementation. Supplementation is not authorized without SHAPE approval.

3. Interim Changes. Interim changes are authorized when approved by the Director of Staff Operations (DOSO)

4. Purpose. To designate defensive measures against Low Level Radiological Hazards that may be encountered during military operations.

5. Table of Contents

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1-1. BACKGROUND.

a. During military operations, hazards not normally considered significant during wartime may become important and impact on operations. These hazard may be more significant during operations other than war such as peace support and peacekeeping. One of the hazards that may confront ACE Forces are radiological hazards that do not occur from a nuclear detonation. These hazards may occur from inadequate nuclear waste disposal, deterioration of nuclear power facilities and damage to institutions that routinely use radioactive material/sources and terrorism.

b. ACE forces may expect to encounter two levels of radiological hazard.

(1). Operationally Significant Level Radiation (OSLR) exposure that produces effects of immediate military relevance. The dose received from these exposures are comparable to those from the detonation of a nuclear weapon and are in the range of 70 Centigray (cGy) and above. Common effects along the radiological dose spectrum include reduced military effectiveness (beginning at 70 cGy) due to nausea and can include death at doses above 300 cGy.

(2). Low Level Radiation (LLR) exposure produces a risk to soldiers of long term health consequences. The doses received from these exposures are higher than those routinely received by health physics workers and the general public and are in the range from background radiation to 70 cGy. The primary consequence of exposure may be induction of cancer in the longer term post exposure. Additional health risks that may occur are teratogenesis and mutagenesis and their associated psychological and social consequences. The hazard from LLR may result from Alpha, Beta or Gamma radiation.

c. This directive will outline policy and procedures for ACE force protection against Low Level Radiation. Wherever applicable the policy will reference current NATO Standardization Agreements, Allied Tactical Publications and ACE Directives and will follow standard NATO concepts and doctrine.

1-2. POLICY. The following general policies apply with regards to exposure of ACE forces to known radiological hazards:

a. Deliberate exposure of ACE forces to a radiological hazard shall not be permitted unless it is required by military necessity.

b. All exposures of soldiers to radiological hazards during operations must be kept as low as reasonably achievable consistent with military necessity.

c. Detailed planning and coordination for the conduct of operations in the area of a radiological hazard is essential.

d. All levels of ACE command should keep a totally open flow of information

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regarding the existence and status of radiological hazard areas within the military structure. However, Commanders should be aware that potential belligerents could use radiological hazards to increase tensions. Therefore, Commanders shall apply an appropriate level of security with regards to release of this information to civil authorities and the general public.

e. Detailed and accurate record keeping is a prerequisite if operations in a radiological hazard area are approved. Record keeping of individual soldier exposures as a dose control measure shall be conducted.

f. Commanders shall ensure subordinate formations are aware of this policy and have the appropriate equipment and personnel to implement it. When available, individual dosimetry for all forces shall be used.

g. Formations that do not possess the appropriate equipment, personnel and training as described in this document and other relevant NATO standards shall not be used in radiation hazard areas.

h. Commanders shall consult with all appropriate staff specialists prior to any operations in radiological hazard areas. At a minimum, this consultation shall include the NBC Defence Officer, Legal Officer, Medical Officer and Public Affairs Officer. When possible the Medical Officer shall have an appropriate knowledge of radio-biology.

i. Commanders must be cognizant of the possibility of serious long term medical effects and legal liabilities involved with exposure to the lower levels of radiological hazards.

1-3. PROCEDURES. The following procedures apply to ACE forces performing operations in an area where there is a risk of exposure to low level radiological contamination. For purposes of this directive the operational commander is defined as an Army Division level or equivalent commander.

a. Intelligence - Prior to entry into the area, intelligence assets shall provide the ACE operational and local commanders with suspected areas of radiological hazard. The intelligence community shall provide an assessment of the risk (High or Low) of radiological hazard in each suspected area. When possible, details concerning the extent, source and type of hazard shall be provided.

b. Required Capability - All units operating in the area of radiological hazards shall have the capability of individual and group total dose dosimetry, radiological dose rate measurement and the appropriate means to record dosimetry once radiological hazard is encountered. Radiological dose rate and total dose measuring instruments shall have the ability to measure at least .0001 cGy/hour. It is essential for dose rate instruments to measure alpha and beta emitting particles as well as gamma radiation.

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c. Actions upon the identification of a High Risk of a Suspected Radiological Hazard

(1). Upon receipt of an intelligence estimate the high risk radiological hazard, the operational commander shall order an exclusion area around the location. The commander shall establish a minimum exclusion zone of a 1KM radius around the suspected radiological hazard. The commander shall direct an evacuation of all ACE forces in the zone until appropriate follow on actions, as described in this directive, are accomplished. If necessary, essential aviation assets are permitted to transit the exclusion zone at a height of at least of 175 metres.

(2). If the excluded area is not planned for use by military forces then subsequent actions concerning the hazard become a civilian responsibility. However, if military necessity dictates that ACE forces will be required to operate near or at the suspect location the operational commander shall direct the conduct of an NBC Survey to determine the extent of the hazard.

(a). Prior to the survey mission the theatre commander shall issue Operational Exposure Guidance designating a maximum Radiation Exposure State in accordance with the enclosed Low Level Radiation Operational Exposure Guidance. During Operations Other Than War the theatre commander is limited to RES Categories 1A through 1D. RES Category 1E is limited to wartime operations only and intentional exposures in this category require additional justification.

(b). The following elements conduct the NBC Survey:

1. Supporting NBC units equipped with NBC Reconnaissance assets.

2. NBC Survey Teams who are organized and adhere to standards of proficiency in accordance with STANAG 2150, "Standards of Proficiency for NBC Defence" and ACE Directive 75-3, "NBC Defence Organization, Equipment and Training" for ACE Headquarters and Formations Under OPCON of SACEUR."

(c). Prior to the survey mission the team will determine the average radiological background level in a local area known to be free of contamination. The turn back dose rate for a Low Level Radiation survey is .0003 cGy/hour. Upon reaching that dose rate the survey team will back out of the area until a dose rate reading of .0002 cGy/hour is reached. This point is considered to be the outside limit of the radiological hazard.

(d). The survey of the radiological hazard area is to be

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accomplished in accordance with STANAG 2112, "NBC Reconnaissance". However, the survey team will only survey to determine the outside limits of the radiological hazard. Under no circumstances are they to cross the boundary of contamination to make a complete survey. This will preclude unnecessary exposure to contamination.

(e). The survey team shall subsequently mark the hazard area in accordance with STANAG 2002, "Warning Signs for the Marking of Contaminated or Dangerous Land Areas, Complete Equipments, Supplies and Stores". However, due to the existence of a Low Level Radiation hazard, survey units are required to record all readings above .0002 cGy/hour and mark the associated areas.

(3). Units operating near the boundaries of the exclusion area prior to completion of an NBC survey shall initiate continuous monitoring using unit level dose rate monitoring equipment. Units shall immediately report radiological detection to higher level headquarters. This is done using the standard NBC-4 format. However, the report is identified as an NBC-4 ROTA report. Line Hotel will indicate NR2 (Nuclear Release Type 2) as the type of agent in all reports. Line Gentext will indicate any other information about the source as applicable. Line X Ray will indicate the Grid Coordinates for the outside limit of the radiological hazard. Line Romeo is not used. All other lines of the NBC-4 report remain the same as reporting a traditional NBC-4 Nuclear report. When entering data in Line X Ray the survey team shall enter decimals of Centigray/Hr readings if the readings are below 1 Centigray/Hr.

(4). Once all survey results are completed, they shall be compiled by the operational units NBC Defence Cell and an overlay that outlines the extent of the radiological hazard shall be produced. These predictions shall be sent via NBC-5 message to all units in the area of operations. The message shall be identified as an NBC-5 ROTA report. The report is formatted as follows:

Line Alfa	Strike Serial Number
Line Delta	Date Time Group of Initial Detection
Line Hotel	Type of ROTA Release (NR2 for LLR)
Line Tango	Date Time Group of Latest Survey
Line X Ray	Grid Coordinates indicating the outside limit of the Radiological hazard
Line Gentext	Additional Information (More detailed survey results)

(5). The NBC Defence Officer of each operational headquarters in theatre shall maintain a current list of all confirmed, suspected and potential radiological hazards within his area of operations. The NBC Defence Officer at the highest operational headquarters shall monitor the status of these areas and make periodic updates for issue to ACE units.

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d. Actions upon Identification of a Low Risk of a Suspected Radiological Hazard - The actions of the operational commander in this instance are quite similar but vary slightly with regard to initial steps. As the suspected area only has a low probability of hazard, the operational commander should not initiate an exclusion area. If possible, the operational commander shall initiate an NBC Survey prior to units entering the area. If contamination is detected the procedures in Paragraph 1-3.c. apply.

e. Once the determination is made that a suspected radiological hazard area is in fact clear it may be removed from the current list of radiological hazard areas. However, if it is confirmed that there is radioactive materiel present but is not currently hazardous, the site shall remain on the current list of radiological hazard areas as a potential site. Units operating in the vicinity of potential radiological hazard areas shall initiate periodic monitoring.

f. Operations within Confirmed Radiological Hazard areas - If military necessity requires units to operate in a confirmed radiological hazard area the Operational Commander must initiate dose control measures as part of the operation and employ the procedures in the paragraph. It is assumed that all actions outlined in Paragraph 1-3.c, especially with regards to exclusion zones and evacuation, have occurred.

(1). Prior to deliberate operations in an identified radiological hazard area.the Operational Commander will direct a detailed NBC survey of the area to determine the exact hazard and the associated radiological dose rates. The survey may require radiological specialist teams not normally available in national military operational formations. If required, the Operational Commander shall request the appropriate assistance from national military authorities. Once the survey is complete the results will be transmitted to appropriate operational commands via the NBC-5 report.

(2). Prior to the survey and subsequent operations in the area, the Theatre Commander must determine what risk he is willing to subject his soldiers to as part of the operation. The Theatre Commander will use the enclosed Low Level Radiation Operational Exposure Guidance (Annex A). The Theatre Commander shall issue Operational Exposure Guidance designating a maximum Radiological Exposure State (RES) for all individuals that must perform the mission. This RES shall be developed in consultation with those staff specialists listed in Para 1-2.g. above. During Operations Other Than War the theatre commander is limited to RES Categories 1A through 1D. RES Category 1E is limited to wartime operations only and intentional exposures in this category require additional justification.

(3). All Commanders must ensure that once a decision to allow exposure to any level of radiation is made, radiation dose management systems are initiated in accordance with national regulations. The Commander shall ensure that the dose a soldier receives is accurately recorded upon each radiological exposure and that the total dose is annotated in his individual

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national medical record in accordance with national regulations.

(4). The theatre commander shall ensure that the appropriate medical and NBC Cells are tasked to receive, monitor and maintain all radiological data in accordance with national regulations.

(5). If a unit encounters higher than expected radiation and is in danger of exceeding the designated RES level, it must report the situation, withdraw from the area, if militarily acceptable, and receive further guidance from the Commander.

g. Other Actions Relevant to Exposure to Radiological Hazards

(1). Individual Protection - While in a radiological hazard area individuals shall wear clothing that will not allow dust to cause injury to exposed skin. All exposed skin shall be covered to prevent deposition of radioactive dust Individuals in the radiological hazard area shall wear respiratory protection to ensure inhalation of radioactive dust does not occur.

(2). Monitoring of Consumables - Commander's shall direct the monitoring of local produce, water and foodstuffs that may have been exposed to radiological hazards, prior to their issue to ACE forces.

(3). Hazard Area Restoration - Removal of the radiological hazard is not a military mission unless the Commander has a clear need for the facility out of military necessity. Commanders shall involve Civil-Military affairs officers once the extent of the radiological hazard is realized to ensure coordination is conducted with the civilian authorities for site restoration.

(4). Decontamination - Once operations in a radiological hazard area are complete, all equipment shall be monitored for radiological contamination. If contaminated, equipment shall be decontaminated to the lowest level achievable with military means prior to further use.

FOR THE SUPREME ALLIED COMMANDER, EUROPE:

J T HOLMES
Brigadier, UK Army
Director of Staff Operations

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ANNEXES:

A. Low Level Radiation Operational Exposure Guidance

DISTRIBUTION:

B, G, BB.

AMENDMENTS/COMMENTS

Users of this directive are invited to send amendments/comments and suggested improvements to SHAPE.
IHSC, Staff support Branch (Attn: SHPSP)

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ANNEX A TO
AD 80-63
DATED
02 AUG 1996

GUIDANCE LOW LEVEL RADIATION OPERATIONAL EXPOSURE

TOTAL CUMULATIVE DOSE (cGy) See Notes 1, 2 and 3	RES CATEGORY	STATE See Notes 4 and 5	ACTIONS
< 0.05 cGy	0	NO RISK	NONE
0.05 TO 0.5 Cgy	1A	NORMAL RISK	RECORD INDIVIDUAL DOSE READINGS INITIATE PERIODIC MONITORING
0.5 TO 5 cGy	1B	MINIMAL RISK	RECORD INDIVIDUAL DOSE READINGS CONTINUE MONITORING INITIATE RAD SURVEY PRIORITIZE TASKS ESTABLISH DOSE CONTROL MEASURES AS PART OF OPERATIONS
5 TO 10 cGy	1C	LIMITED RISK	RECORD INDIVIDUAL DOSE READINGS CONTINUE MONITORING/UPDATE SURVEY CONTINUE DOSE CONTROL MEASURES EXECUTE PRIORITY TASKS ONLY (See Note 6
10 to 25 cGy See Note 7	1D	INCREASED RISK	RECORD INDIVIDUAL DOSE READINGS CONTINUE MONITORING/UPDATE SURVEY CONTINUE DOSE CONTROL MEASURES EXECUTE CRITICAL TASKS ONLY (See Note 6
25 TO 70 cGy See Note 8	1E	SIGNIFICANT RISK	RECORD INDIVIDUAL DOSE READINGS CONTINUE MONITORING/UPDATE SURVEY CONTINUE DOSE CONTROL MEASURES EXECUTE CRITICAL TASKS ONLY

NOTES:

1. Dose is uniform to the entire body due to whole body irradiation. This table does not consider the intake of radioactive material. This is assumed due to employment of effective respiratory protection and other measures.
2. All doses should be kept as low as reasonably achievable (ALARA). This will reduce individual soldier risk as well as retain maximum operational flexibility for future employment of exposed soldiers.
3. The use of the measurement Milli Sieverts (mSv) is preferred in all cases. However, due to the fact that normally the military has only the capability to measure Centigray (cGy), as long as the ability to obtain measurements in mSv is not possible, ACE forces will use cGy. For whole body Gamma irradiation : 1 cGy = 10 mSv.
4. Risk is of long term health consequences primarily induction of fatal cancer starting two years post exposure. Total lifetime risk is assumed to be four to seven percent per 100 cGy (= 1000 mSv). This is in addition to the 20-25% incidence of fatal cancer among the general population. Additional health risks that may occur are teratogenesis and mutagenesis and their associated psychological and social consequences.
5. It must be noted that higher radiation dose rates produce proportionally more other health risk than the same total dose given over a longer period.
6. Examples of priority tasks are those missions to avert danger to persons or to prevent damage from spreading. Examples of critical tasks are those missions to save human life.
7. During peacetime this dose shall not be exceeded except to save human lives.
8. RES category 1E covers a wide range of dose and its lower level (25cGy = 250 mSv) is the peacetime maximum operational does in many NATO nations. This category is normally only applicable in wartime. Intentional exposures to doses in this category (25-70 cGy = 250 - 700 mSv) require additional justification.

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