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Potential Radiation Exposure in Military Operations: Protecting the Soldier Before, During, and After

Committee on Battlefield Radiation Exposure Criteria, Institute of Medicine

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Potential Radiation Exposure in Military Operations

Protecting the Soldier Before, During, and After

Committee on Battlefield Radiation Exposure Criteria
Fred A. Mettler, Jr., *Chairman*

Susan Thaul and Heather O'Maonaigh, *Editors*

Medical Follow-up Agency
INSTITUTE OF MEDICINE

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Washington, D.C.

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The serpent has been a symbol of long life, healing, and knowledge among almost all cultures and religions since the beginning of recorded history. The serpent adopted as a logotype by the Institute of Medicine is a relief carving from ancient Greece, now held by the Staatliche Museen in Berlin.

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Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the Institute of Medicine in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and the draft manuscript remain confidential to protect the integrity of the deliberative process. The committee wishes to thank the following individuals for their participation in the review of this report:

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While the individuals listed above have provided constructive comments and suggestions, it must be emphasized that responsibility for the final content of this report rests entirely with the authoring committee and the Institute of Medicine.

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Preface

In 1996, NATO issued guidance for the exposure of military personnel to radiation doses different from occupational dose levels, but not high enough to cause acute health effects-and in doing so set policy in a new arena. Scientific and technological developments now permit small groups or individuals to use, or threaten to use, destructive devices (nuclear, biological, chemical, and cyber-based weaponry, among others) targeted anywhere in the world. Political developments, such as the loss of political balance once afforded by competing superpowers, have increased the focus on regional and subregional disputes. What doctrine should guide decisionmaking regarding the potential exposure of troops to radiation in this changed theater of military operations? In 1995, the Office of the U.S. Army Surgeon General asked the Medical Follow-up Agency of the Institute of Medicine to provide advice.

This report is the final product of the Committee on Battlefield Radiation Exposure Criteria convened for that purpose. In its 1997 interim report, *Evaluation of Radiation Exposure Guidance for Military Operations,* the committee addressed the technical aspects of the NATO directive. In this final report, the committee reiterates that discussion and places it in an ethical context.

Focusing on potential exposure of military personnel to radiation doses up to 700 millisievert, the committee addresses details of dosimetry, radiation physics, and the medical follow-up of potential, subsequent tumor development. The ethical framework presented in this report applies to potential harms beyond those posed by radiation alone. Soldiers face bullets, explosive devices, climatic and weather extremes, and endemic infections, as well as nuclear, chemical, and biological agents. On a daily basis, commanders in the Pentagon and in the field face decisions that affect the safety of the troops in their charge. This committee lays out a framework for those decisions, be they at a mission's planning stage, during its operation, or in its immediate or long-term aftermath. In weighing the risks of a mission that may involve radiation doses to its participants, a com

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mander must somehow quantify not only the immediate and long-term effects of radiation, but also the risks of alternative, radiation-free, approaches to the same mission. To do this, a commander must have information that is understandable and useful. The components of the committee's framework should apply, therefore, in all instances of exposure of military personnel to hazards, during times of war and during times of peace.

The committee commends the Office of the U.S. Army Surgeon General for the steps it has taken to protect American soldiers. The committee offers a framework to help ensure that soldiers are not put in harm's way without adequate justification; that, when such exposure is deemed necessary, commanders have the information and training necessary to act to limit its extent; and that government agencies work together in a committed, appropriate way to follow-up the health status of those individuals who are at risk of related long-term consequences. These tasks certainly are not easy; without appropriate training and information, they are impossible.

Fred A. Mettler, Jr., Chairman

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The committee and staff are once again grateful to LTC Carl A. Curling (Medical, Nuclear, Biological, and Chemical Staff Officer), program officer at the Office of the U.S. Army Surgeon General, for his support of the project.

Many individuals participated in the committee-organized briefings and a workshop. During these sessions, representatives from the Departments of Veterans Affairs and Defense, veterans groups, and others learned how we, as a committee, perceived the scope of our task. In turn, we learned facts, history, and what others hoped to gain from our work. We thank them all (see Appendix B for a full listing) for their contributions to the committee's work and for their efforts to protect military personnel from harm of all kinds.

In addition to the staff who worked directly on this project, others at the Institute of Medicine and the National Research Council contributed to this report. We thank Sue Barron, Claudia Carl, Mike Edington, Sharon Galloway, and Linda Kilroy for their efforts. Thank you, also, to consulting editor Michael Hayes and James G. Hodge, Jr., Adjunct Professor of Law, Georgetown University, for assistance with this report.

It is difficult to know where to place the next acknowledgment and what exactly to say. We wish that Christopher Johnson could have continued his excellent work with us through to the completion of the project. A little over a year ago, Chris left the Institute of Medicine upon learning that he had a brain tumor. He is at home with his family. We miss him.

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Radiation Unit Conversion Chart

0.001 rem	=	1 mrem	=	0.01 mSv		
0.01 rem	=	10 mrem	=	0.1 mSv		
0.1 rem	=	100 mrem	=	1 mSv	=	0.001 Sv
I rem	=	1,000 mrem	=	10 mSv	=	0.01 Sv
10 rem	=		=	100 mSv	=	0.1 Sv
100 rem	=		=	1,000 mSv	=	1 Sv
1,000 rem	=				=	10 Sv
0.001 rad	=	1 mrad	=	0.01 mGy		
0.01 rad	=	10 mrad	=	0.1 mGy		
0.1 rad	=	100 mrad	=	1 mGy	=	0.001 Gy
1 rad	=	1,000 mrad	=	10 mGy	=	0.01 Gy
10 rad	=		=	100 mGy	=	0.1 Gy
100 rad	=		=	1,000 mGy	=	1 Gy
1,000 rad	=				=	10 Gy

NOTE: Sievert is equivalent to rem; gray is equivalent to rad. (Radiation units are discussed in Chapter 2.)

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Acronyms

ACE	Allied Command Europe
ACHRE	Advisory Committee on Human Radiation Experiments
AIDS	Acquired immunodeficiency syndrome
ALARA	As low as reasonably achievable
AMC	Army Materiel Command
ARNGUS	Army National Guard of the United States
ATSDR	Agency for Toxic Substances and Disease Registry
BEIR	Biological Effects of Ionizing Radiation
C kg^{-1}	Coulombs per kilogram
CFR	Code of Federal Regulations
cGy	Centigray
CT	Computerized tomography
DA	U.S. Department of the Army
DLA	U.S. Defense Logistics Agency
DNA	Deoxyribonucleic acid
DoD	U.S. Department of Defense
DoDI	U.S. Department of Defense Instruction
DOE	U.S. Department of Energy
DSWA	Defense Special Weapons Agency (now the Defense Threat Reduction Agency)
DT-236, IM-93	Specific dosimeters
EPA	U.S. Environmental Protection Agency

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FTCA	Federal Torts Claims Act
GM	Geiger-Mueller detector
Gy	Gray
HIV	Human immunodeficiency virus
HQDA	Headquarters, Department of the Army
IAC	International Advisory Committee, International Atomic Energy Agency
IAEA	International Atomic Energy Agency
IARC	International Agency for Research on Cancer
ICRP	International Commission on Radiological Protection
IOM	Institute of Medicine
IQ	Intelligence quotient
IRBs	Institutional review boards
LET	Linear energy transfer
LLR	Low level radiation
MFUA	Medical Follow-up Agency
mGy	Milligray
mrad	Millirad
mrem	Millirem
mSv	Millisievert
mSv y^{-1}	Millisievert per year
NATO	North Atlantic Treaty Organization
NBC	Nuclear, biological, and chemical
NCI	National Cancer Institute
NCRP	National Council on Radiation Protection and Measurements
NRC	U.S. Nuclear Regulatory Commission
OPRR	Office for Protection from Research Risks, National Institutes of Health
OTSG	Office of the U.S. Army Surgeon General
PTSD	Posttraumatic stress disorder
R	Roentgen
RES	Radiation Exposure State
SHAPE	Supreme Headquarters, Allied Powers Europe
SI	International System of Units

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STANAG	Standardized Agreement
Sv	Sievert
TLD	Thermoluminescent dosimeter
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
U.S.	United States
USAIRDC	U.S. Army Ionizing Radiation Dosimetry Center
USANCA	U.S. Army Nuclear and Chemical Agency
USAR	U.S. Army Reserve
USC	United States Code
VA	U.S. Department of Veterans Affairs
w_R	Radiation weighting factor
w_T	Weighting factors for tissue

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Summary

This is the final report of the Committee on Battlefield Radiation Exposure Criteria, produced under the auspices of the Medical Follow-up Agency of the Institute of Medicine, National Academy of Sciences. In it, the committee addresses technical and ethical aspects of military radiation protection and safety policies applicable in instances of the potential exposure of military personnel to radiation doses that are less than those that cause acute effects but that are associated with a long-term risk of subsequent cancers. At the request of the Surgeon General of the U.S. Army, the project's sponsor, the committee focused its interim report (IOM, 1997) on the scientific merit of proposed North Atlantic Treaty Organization (NATO) guidelines for this category of military operations. This final report summarizes the general technical points of the interim report and expands the committee's discussion of the ethical considerations, education, training, and the decisionmaking process involved in initiating appropriate actions when military personnel may be at risk of exposure to radiation doses up to 700 millisievert (mSv). The committee also includes consideration of the evaluation of the long-term health effects of radiation.

In this summary, the committee presents a synopsis of its recommendations in Table S-1; it then proceeds to layout the study's history and a brief outline of material in the interim report. The committee divides the rest of this Summary into three parts. The first section reprints the list of recommendations from the interim report. For discussion of those points, refer to Chapter 5 of the full report. Next, the committee highlights the concepts of justification for imposing risk on others; procedures for optimizing the risk situation to protect soldiers while also meeting military objectives; policies for recording, maintaining, and using dose information regarding individual soldiers; and programs that may be used to identify potential adverse health effects that become apparent long after the exposure. This summary concludes with the five recommendations that the committee presents in the report's final chapter.

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TABLE S-1. Report Recommendations

1. Balancing future and present harm	When making decisions, commanders should consider long-term health effects that any action may have on their troops.
2. Philosophy of radiation protection	The U.S. Department of Defense (DoD) should develop and clearly express an underlying philosophy for radiation protection, including justification and optimization.
3. Communicating risk	Military personnel should receive appropriate training in both radiation effects and protection in a way that neither inappropriately minimizes effects nor creates unwarranted fear.
4. Radiation dosimetry, records, and reporting	Troops expected to be in radiation areas should have individual dosimeters. DoD should also maintain exposure records, with strong privacy assurances, and make these available to the exposed individuals.
5. Follow-up	Given the tests that are currently available and their limitations, monitoring programs for cancer (whether spontaneous or radiogenic) should be limited to those testing and monitoring programs included in guidelines for the general population.

HISTORICAL PERSPECTIVE AND RATIONALE

During the Cold War era, NATO and the U.S. Army instituted policies involving radiation dose limits and control measures to be used in the event of global nuclear war. The U.S. Army also has in place a radiation safety and protection program—comparable to civilian occupational protection programs-for personnel involved in routine duties involving possible radiation exposure. In the post-Cold War setting, however, military scenarios involving radiation exposure rarely reflect global nuclear war but more often consider limited nuclear exchanges, terrorist actions with improvised nuclear devices, conventional explosives employed as a means of disseminating radioactive materials, or nuclear power plant accidents. Military operations involving such situations are not covered by either the guidelines designed for nuclear war or the programs in effect for occupational duties.

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 in Bosnia. In response, SHAPE staff, with U.S. Army participation, developed the Allied Command Europe (ACE) Directive Number 80-63, "ACE Policy for Defensive Measures against Low Level Radiological Hazards during Military Operations" (NATO, 1996).

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The ACE Directive (NATO, 1996) 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. The Directive touches on planning, coordination, security, dosimetry, recordkeeping, training, equipment, expertise, and commander responsibilities. It includes a chart (excerpted here from the Directive as Table S-2 and as Table 4-1 in Chapter 4 of this report) that defines radiation exposure state categories and outlines actions to be taken when personnel receive (or are at risk of receiving) specified levels of radiation dose. The operational exposure guidance presented in the Directive was the focus of the committee's interim report.

RADIATION PHYSICS, RADIATION BIOLOGY, AND RADIATION SAFETY AND PROTECTION

The first few chapters of this report include basic information about (I) radiation physics and radiation biology, (2) accepted standards of U.S. and international civilian and emergency radiation protection and safety practices, and (3) current U.S. Army radiation program practices. Next, the committee discusses the U.S. Army's approach to addressing issues relating to situations in which troops may be at risk of receiving radiation doses up to as much as 700 mSv in light of standard civilian practices, including the consideration of risk assessment, communication, training, education, commander decisionmaking, reporting, and follow-up. Taken together, these considerations form the building blocks of an ethically based approach to the planning, implementation, and follow-up of operations involving potential radiation exposure.

RECOMMENDATIONS FROM THE INTERIM REPORT*

The committee recommends that the U.S. Army:

Underlying Philosophy

1. Provide soldiers the same level of radiation protection as civilians working in similar environments.
2. Develop and state an explicit radiation protection philosophy that defines missions as falling under the framework of either a practice or an intervention.

* *An Evaluation of Radiation Exposure Guidance for Military Operations: Interim Report.* J.C. Johnson and S. Thaul (eds.). Washington, D.C.: National Academy Press, 1997.

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TABLE S-2. Draft (August 2, 1996) Operational Exposure Guidance for Low Level Radiation

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

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[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 because of the employment of effective respiratory protection and other measures. All doses should be kept as low as reasonably achievable (ALARA). This will reduce the risk to the individual soldier and will retain maximum operational flexibility for future employment of exposed soldiers. The use of the measurement millisievert (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 millisievert is not possible, ACE forces will use centigray. For whole-body gamma irradiation, 1 cGy is equal to 10 mSv.

[b] Risk is of long-term health consequences, primarily induction of fatal cancer starting 2 years postexposure. Total lifetime risk is assumed to be 4 to 7 percent per 100 cGy (1,000 mSv). This is in addition to the 20 to 25 percent 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. 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.

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

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

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

SOURCE: NATO. ACE Policy for Defensive Measures against Low Level Radiological Hazards during Military Operations. ACE Directive Number 80-63. Brussels, Belgium: Supreme Allied Headquarters Europe, August 2. 1996 (with minor editorial revisions).

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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.

Terminology

4. Not use the term *low level* to describe the radiation dose range of 50 to 700 milligray (mGy) (5 to 70 rad).
5. Use terms other than *no risk* and *normal risk* for the risk state categories labeled RES [radiation exposure state] 0 and RES IA in the table of exposure guidance in Annex A of the ACE Directive.
6. Avoid the term *radiological hazard* when describing the exposure of soldiers to radiation, unless the hazard refers to a specific detrimental effect.

Prospective Risk Assessments

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.
8. Reconsider its absolute requirement that soldiers wear protective equipment within an exclusion zone as defined in the ACE Directive.
9. Make a clear distinction between military intelligence threat estimates and radiation risk estimates.
10. Develop explicit requirements to define when individual radiation monitoring is required in the field.

Dosimetry

11. Review its dosimetry capabilities and determine if they are adequate to support the use of the Operational Exposure Guidance in the ACE Directive.
12. Increase the 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).
13. Not assume, as the ACE Directive does, that internal doses will be zero because respiratory protection will be used.
14. Review its capability to measure airborne radioactive contamination.
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.
16. Adopt the millisievert (mSv) as the standard unit of effective dose and milligray (mGy) as the unit of absorbed dose.

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17. Clearly define the time over which doses are to be accumulated for assignment of RES levels in the Operational Exposure Guidance in Annex A of the Directive.
18. Review and revise doctrine and procedures on dosimetry to ensure that 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.

Reference Levels for Operational Exposure Guidance

19. Include radiation doses from internal sources (e.g., from inhaled airborne radioactivity) in applying reference levels in Operational Exposure Guidance.
20. Clearly specify what actions are recommended at each reference level in the Operational Exposure Guidance.
21. Restructure the table of Operational Exposure Guidance to account for the uncertainty of dose estimates in interventions.
22. Develop separate Operational Exposure Guidance for managing practices (routine tasks involving radiation exposure) in the context of a military operation.

ETHICAL FRAMEWORK

Justifying Placing Individuals at Risk of Harm

There is a general ethical principle that one should not put individuals at risk of harm. Exceptions to this principle require justification.

There are standard, not mutually exclusive, ways of looking at how to ethically justify placing some at risk for the benefit of others: *consent* and *role-related responsibility*. In many circumstances it is considered ethically justifiable to place individuals at risk of harm for the benefit of others if they consent to that imposition. To be ethically valid, the consent must be based on an adequate understanding of the nature and implications of the risk, and the person must be free to refuse. Another way of thinking about risk focuses on role responsibility. Certain roles, like soldiering, carry with them an obligation to bear risk for the benefit of others. There are both voluntary and involuntary assumptions of roles; it does not necessarily follow that because a role was not voluntarily assumed that it does not carry with it some socially acceptable and morally justifiable risk. For example, whether they enlist or are conscripted, all soldiers assume the role-related risks of military service.

Justifications of consent and role responsibility do not exhaust the ethical considerations associated with the imposition of risk. Several other ethical conditions must be satisfied.

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There must be an analysis that supports, if not demonstrates, that no more risk than is necessary to achieve the goal is being imposed or placed on the individual. This is the optimization principle of radiation protection, implemented by ALARA—as *low as reasonably achievable—procedures.* In addition, the ethical duty to minimize risk includes taking steps to minimize the likelihood that the risk will materialize into harm. In this context, the duty includes the responsibility for appropriate follow-up of exposed and potentially exposed individuals. Dosimetry, recordkeeping, and medical monitoring all support postexposure efforts to minimize harm.

There is the duty to treat with respect the persons being placed at risk. This includes *disclosure* of the risk to the person both before and after the exposure and maintenance of the *privacy* of the person who has been put at risk of harm, enabling the individual to have control over access to information about his or her exposure and the uses that others might make of this information. One could provide *remedy* or *compensation* for the simple assumption of risk or limit the provision of a remedy only to circumstances when the risk materializes into harm.

Finally, there is the set of considerations having to do with *justice.* Who is to be exposed? Are any of the individuals or groups particularly vulnerable, particularly open to exploitation, or particularly burdened by preexisting harms or risks? How should one weigh deaths or injuries that will occur in the present against deaths or illness that will occur in the future? Does it matter morally if, in choosing the nonradiation threat, the harm would befall only a small number of identifiable soldiers, while, if the choice were radiation exposure, it cannot be known at the time who among those exposed will subsequently suffer the harm'?

A few features of the military context further increase the ethical burden on both commanders and the government with respect to soldiers. Commanders have much more authority over soldiers than civilian employers have over their employees. Members of the military are obligated to follow all lawful orders, even those that put them at risk of death or disability. Medical and related records (including radiation exposure information) are vital to ensuring that ethical consideration of possible radiation injury has been taken into account in addressing the military objective.

Training, Recordkeeping, and Reporting

Throughout the report, the committee discusses the topics of training, recordkeeping, and reporting in sequence. In a good radiation protection program all three must be intricately interwoven. Training should impart some basic understanding of radiation, communicate the risk, help the soldier to understand the ramifications of risk perception, and then place that knowledge in a context whereby the risks associated with radiation exposure can be compared with other radiation- and non-radiation-related risks. These comparisons should be tested both by experts in risk communication and with groups of laypeople to ensure that the

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information is understandable and not misleading. The soldier then can draw upon this foundation to (1) protect himself or herself and others during an exposure situation, (2) know which pieces of information are important to obtain and record, (3) act to notify whomever should know about exposures or effects, and (4) use his or her own dose report to help guide his or her own future occupational, avocational, and health care activities. In addition, through training, the military attempts to teach commanders how to decide when it is appropriate to put subordinates at risk (justification) and how to do so to minimize short- and long-term harm while also achieving the military mission (optimization).

Therefore, training content includes conveying the value of information (e.g., records are important and notification of personnel is important) and the lesson that recordkeeping and notification procedures are valuable only if the soldier knows (through training) what to measure and how to do so, what to record, and what to do with that information once it is recorded.

The common thread is communication. Accurate and appropriate information must be maintained so that it is available to be given to the right people at the right time. Furthermore, this communication must be exercised within an ethical framework in which the government seeks to meet its military objectives, protect the health of military personnel, and take responsibility for the health consequences of its decisions.

Information is vital to sustaining protection. When existing technology allows detection of radiation exposures, advance notice of potential radiation exposures is the goal. When feasible, radiation levels should be monitored in settings of suspected exposure. The levels of radiation that may involve short- or long-term risks need to be predetermined. Chains of command should be prepared to disseminate radiation warnings quickly and efficiently. If possible, soldiers should be equipped with devices that detect levels of radiation in the operational field in cases in which significant radiation exposure is expected. They should be fully knowledgeable of the operation of these devices and interpretation of the readings displayed by these devices.

Since the U.S. military is also the employer of the soldier, the military has an independent obligation to the volunteer to minimize the risks as much as reasonably possible. This can be done in a number of ways, including planning, the use of protective equipment, and the exploration of less risky alternatives.

In addition to the requirement that the U.S. Department of Defense (DoD) maintain radiation exposure data on all its potentially exposed personnel, the committee strongly recommends that each military member so exposed be provided annually, and on termination of military service, a written document specifying the magnitude of each exposure (if possible) and the location(s) of such exposure(s) during service. A copy of this information can then be made available to the U.S. Department of Veterans Affairs for future determination of disability connected to service in the military and follow-up medical care if required. If possible, the exposure data notification document should include both a listing of the agents to which the person was exposed (e.g., radiation, chemicals, biological exposures, conventional injuries, and stressful situations) and a

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general statement of the potential health consequences related to those exposures. The quality of the information provided will vary depending on whether the military operation was during war or peacetime, with more detail expected during peacetime activities.

With current equipment and personnel capabilities, the Army cannot fully implement the recommendations in this report. However, as the Army prepares and implements new policy it should bear in mind the recommendations as well as the broader discussion of issues in this report.

COMMITTEE RECOMMENDATIONS

The Surgeon General of the U.S. Army requested guidance on the management of military operations in which radiation effective doses might range up to 700 mSv. The committee has formulated recommendations that cover a number of areas. Some of these areas have already been addressed by the military but are included because they are important and the report would not be complete without their consideration.

Balancing Future and Present Harm

Current doctrine and risk evaluation by military commanders focus on acute injuries and fatalities and those factors which potentially affect the ability to achieve a military objective. The U.S. Department of Veterans Affairs deals with long-term health effects and disability. A focus on acute health effects from any cause is still largely appropriate for hostile situations, but it discounts or ignores long-term detriment and is inappropriate for less emergent situations in which the military may be asked to participate.

The U.S. Army asked the committee to consider doses of less than 7(X) mSv. Although no significant acute effects are expected to result from such radiation doses, excess risks of many types of cancer and leukemia have statistically significant associations with doses in this range. Although the long-term effects of radiation are relatively well known, the long-term detriment associated with other exposures or potential exposures, such as psychological stress, are less well understood and quantified. The committee thinks that these should not be ignored.

RECOMMENDATION 1: When making decisions, commanders should consider the long-term health effects that any action may have on their troops.

- This should become standard operating policy.
- In addition, the Department of Defense should attempt to quantify long-term detriment from a number of causes, including radiation, and develop training material and scenarios that address these effects.

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- The long-term effects to be considered in operational decisions should include not only those from radiation but also those from conventional injuries, chemical and biological agents, and psychological stress.

Philosophy of Radiation Protection

A philosophy for dealing with any potential harm should be clearly stated, widely disseminated, ethically based, practical, and comprehensive. This will allow commanders to make informed decisions and be flexible rather than having to deal with prescribed limits when they may be inappropriate or impractical. This philosophy should be focused on minimizing the risk of harm while allowing the performance of the required military objective. There are clearly situations in which radiation exposure is justified because the risk of radiation-induced harm is less than the risks from other hazards associated with the action. A policy that completely avoids radiation exposure is inappropriate and may expose troops, and perhaps others, to larger risks of harm from other, nonradiation, causes.

RECOMMENDATION 2: The U.S. Department of Defense should develop and clearly express an underlying philosophy for radiation protection.

A. The committee suggests application and adaptation of the system recommended by the International Commission on Radio logical Protection.

- This system includes practices as well as interventions.
- These are required to be initially justified (more benefit than risk) and then optimized (minimization of dose) in the context of the situation.

B. The committee recommends that in peacetime or nonemergent situations soldiers should be accorded the same level of protection accorded civilians.

- Those soldiers who may be exposed to radiation dose levels similar to those to which civilian radiation workers are exposed should have the same level of training as civilian radiation workers and should be subject to occupational dose limits.

C. In settings in which an intervention is required and specific numerical dose limits are neither applicable nor practical, the committee recommends that commanders justify the mission (there is more benefit than risk), examine competing risks, and optimize

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the mission (identify ways to minimize dose without jeopardizing the mission).

- Examples of these settings include emergent or lifesaving actions, actions to prevent exposure of large populations, and hostile situations.

Communicating Risk

Training and risk communication are extremely important not only so the troops can adequately achieve their objective but also so they can understand the risks and protect themselves.

RECOMMENDATION 3: Military personnel should receive appropriate training in both radiation effects and protection. Their training will need to vary on the basis of the particular level of potential exposure and upon the task at hand.

- Training may range from task-specific operational briefings to full courses, depending upon the situation.
- Well-crafted, realistic scenarios should be incorporated into training at all levels.
- Potential long-term health consequences from radiation exposure should be included in the discussion of risks.
- The training should put radiation effects in perspective in language that the troops can understand but not in a way that inappropriately minimizes the effects or creates unwarranted fear.
- When long-term risks of harm from sources other than radiation are largely unknown, this should be stated.
- Regardless of current NATO policy, DoD should avoid using the terms *low risk* or *no risk* in training and briefings when radiation levels clearly carry a measurable cancer risk.

Radiation Dosimetry, Records, and Reporting

For risk management during and after a mission, it is important to estimate or quantify current and past exposures. This is optimally done through the use of radiation detection devices, environmental sampling, personnel dosimeters, bioassays, and, possibly, whole-body counting. Even in certain hostile situations when all of these may not be possible, estimates of exposure conditions and dose can still be made. Such information should be available to military personnel during active duty and after discharge.

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RECOMMENDATION 4: A program of measurement, recording, maintenance, and use of dosimetry and exposure information is essential.

A. Troops expected to be in areas where there is a risk of radiation exposure should have individual dosimeters.

B. Systematic individual radiation dose records—for external and internal doses—should be maintained and should follow the soldier from one operational unit to another should be kept.

C. A system that includes the capability to field monitor, and estimate or measure and then record internal doses needs to be developed.

- When appropriate, organ-absorbed doses should be recorded in addition to the effective dose.

D. The U.S. Department of Defense should also maintain exposure records in a confidential manner that contains strong privacy assurances. Records should be kept in a secure form and should be available to the individual.

E. Annually and upon deactivation or discharge, potentially exposed military personnel should be given a written record of their radiation exposures with estimated doses (annual and cumulative), even if they are zero.

- This should be separate from any administratively required occupational recording and notification.
- There should also be an explanation of the implications of these radiation exposures for future health outcomes.
- Even if an operation is classified, there is still a need to provide such information.

Follow-Up

The exposure of troops to agents and situations that may have long-term health effects raises the issue of whether there is any appropriate medical monitoring (screening) that will detect such effects before they are evident clinically and that may positively affect disease progression or outcome. The primary effect in the cumulative radiation dose range that the committee considers in this report is an excess risk of certain types of cancer and leukemia. Unfortunately, at this time only a few screening tests are clearly effective; these tests are used

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to detect breast, cervical, and colon cancers. Physician-directed individual diagnostic testing may be useful in selected situations, particularly when the radiation absorbed doses are extremely high. It should be noted that cancer currently occurs in about 40 percent of the U.S. population (NCI, 1994). For doses in the highest dose range addressed in this report (500-700 mSv), the increased risk of cancer attributable to the radiation dose is about 1/10 the normal baseline cancer incidence rate for unexposed individuals. Although this is a low percentage, a large number of troops exposed at these doses could result in a large number of excess cancers.

RECOMMENDATION 5: Given the tests that are currently available and their limitations, testing and monitoring programs for cancer (whether spontaneous or radiogenic) should be limited to those testing and monitoring programs included in guidelines for the general population.

- Specific periodic screening or medical monitoring of radiation exposed populations is not warranted solely on the basis of the radiation exposure in the dose range considered in this report.
- If effective tests for other cancer types do become available, screening may be useful on the basis of the normal cancer incidence in the general population.
- For persons who have received cumulative effective doses in excess of 50 mSv, the establishment of well-designed and dynamic registries may be helpful in addressing future health-related issues on an individual or population basis.

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1

Introduction

BACKGROUND

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 NATO guidance addresses radiation doses ranging from those governed by civilian—public and occupational—guidelines to the doses above which acute health effects are expected to develop and would be anticipated during a major nuclear conflict. At the request of the U.S. Army Surgeon General, the Institute of Medicine convened an expert committee to evaluate these guidelines from scientific and ethical perspectives. This is the committee's final report. The interim report (IOM, 1997) focused on the scientific merit of this new NATO guidance by responding to the following charges:

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's charge in completing this final report was to advise the Army concerning the following:

1. What general criteria apply in the establishment of exposure guidelines in the gap between civilian occupational exposure levels and performance degrading exposure levels?

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2. How should risks for acute trauma (e.g., from gunshot, mines, artillery fire, etc.) be weighed against the possible long latency effects of radiation (e.g., tumors developing 30 years after exposure)?

These questions should consider:

- Ethical foundations for establishing and operating standards for radiation exposure. What are the ethical considerations for commanders and medics? What are the responsibilities for prevention, treatment, and follow-up if commander decides to expose?
- Scientific bases for estimating effects of radiation and conventional risks on the battlefield (in both combat and peacekeeping scenarios).
- Operational scenarios provided by the Army to focus the deliberations of the committee.

Although this final report incorporates the general technical principles discussed in the interim report, it expands on other critical factors, including ethics, risk perception, recordkeeping, training, communication, decisionmaking, and follow-up.

During the Cold War, the U. S. Army established radiation dose limits and controls for soldiers based on a scenario of global nuclear war (HQDA, 1994; NATO, 1986). Battlefields were expected to be highly contaminated with radioactive material. In anticipation of such scenarios, 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 set at the threshold at which radiation sickness develops.

In the post-Cold War setting, military scenarios involving radiation exposure rarely reflect global nuclear war but more often consider limited nuclear exchanges, terrorist actions with improvised nuclear devices, conventional explosives employed as a means of disseminating radioactive materials, or nuclear power plant accidents. In these scenarios (relative to those during the Cold War), the risk of exposure to radiation would be more limited geographically and the immediate risks to a soldier might be much lower. Except in rare circumstances, the radiation doses received under these scenarios would be well below those that cause serious radiation injuries soon after exposure, yet they could be above the occupational dose limits that are applied to civilian workers and military personnel assigned to routine occupational duties (CFR, 1991). The new NATO guidance addresses protection for soldiers at risk of exposure at levels that could result in doses up to 700 millisievert (mSv). In its interim report, the Committee on Battlefield Radiation Exposure Criteria reviewed this guidance as it is expressed in Allied Command Europe (ACE) Directive 80-63 (NATO, 1996). The U.S. Army, as well as a NATO working group, has continued work on this issue (which the committee addresses in Chapter 4).

During the Persian Gulf War, the U.S. Army recognized the potential for the exposure of soldiers to levels of radiation that exceeded occupational levels but

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that were below levels set in Standardized Agreement (STANAG) 2083, Commanders' Guide on Nuclear Radiation Exposure of Groups (NATO, 1986). During Operation Desert Shield and Operation Desert Storm, the U.S. Army Foreign Service 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 isotopes of cesium and cobalt from radiotherapy sources) on the battlefield.

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 the survival of military operational personnel. In this new era, commanders face missions, such as those that involve peacekeeping and the provision of humanitarian assistance, in nonbattlefield environments, in which the risk of immediately disabling and life-threatening injuries is lower in comparison with the risk of exposures that are possible in wartime situations.

This shift in the nature of military activity has brought with it increased interest in the potential for delayed health effects of battlefield activities (e.g., the potential for the development of a radiation-induced cancer many years after exposure). This is new ethical and doctrinal ground for Army planners, who 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 that might occur among military forces in Europe during the peacekeeping mission in Bosnia. In response, SHAPE staff developed the ACE Directive 80-63, ACE Policy for Defensive Measures against Low Level Radiological Hazards during Military Operations. The U.S. Army participated in the development of NATO radiation protection guidelines for the soldier in the new radiation exposure scenario, with a U.S. Army representative heading the NATO team of experts.

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* 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 [0.7 Gy].
> 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.)

* See Chapter 5, Recommendations 4 to 6, on the terminology in the ACE Directive.

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The ACE Directive (see Appendix A) 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 a radiation hazard, dissemination of hazard information, and personnel protection. Finally, the Directive includes a chart that defines radiation exposure state categories and outlines the actions to be taken when personnel receive (or are at risk of receiving) specified levels of radiation dose. This chart subdivides the dose levels defined in existing guidelines (HQDA, 1994; NATO, 1986) as being of *negligible risk* to *moderate risk.*

Radiation is not a new hazard for service personnel. Approximately 202,000 military service members participated in U.S. nuclear weapons testing between 1945 and the 1963 signing of the Limited Test Ban Treaty (VA, 1997). No fewer than eight laws have been enacted in the years since 1981 in attempts to provide just consideration of claims for compensation for health problems and disabilities that some atomic test participants attribute to radiation exposure.

The National Test Personnel Review program within the Defense Special Weapons Agency was chartered within the U.S. Department of Defense to develop a personnel register and estimate doses for the atomic test participants. Inadequate records for use in estimating the 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 many of these veterans. The history of the veterans involved in the aboveground 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 to radiation. The actions that the U.S. Army has recently taken to control radiation exposures to soldiers at levels that are below the threshold for immediate effects are a significant step in that direction.

In this final report, the committee provides information that is intended to assist the Army in developing both an appropriate radiation protection philosophy and appropriate standards applicable to the wide spectrum of radiation exposure situations that soldiers may encounter.

REPORT LAYOUT

The committee has chosen to structure this final report so that it encompasses most of the information provided and all the recommendations offered in the interim report (IOM, 1997). Most readers, therefore, will need only this sec

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ond volume. The additional detail of the interim report remains available, of course, to any reader.

Chapters 2, 3, and 4 provide a grounding in radiation protection philosophy and science; currently accepted standards of U.S. and international civilian and emergency practices; and current U.S. Army practices. The committee has enhanced all three chapters since their publication in the first report. Sections on training, recordkeeping, follow-up, and legal considerations have been expanded.

Chapter 5 in this report is based on Chapters 5 and 6 of the interim report, which were written to directly relate to a specific (now revised) document of interest to the U.S. Army. For this final report, the committee has reorganized its response to those specific issues so that the information in Chapter 5 can be applied to other current and future policy documents as well. The committee integrates in this chapter descriptions of civilian and military practices (outlined in earlier chapters) with issues raised during the committee's deliberations. New emphasis is placed on risk assessment, communication, training, education, and notification.

Chapter 6 provides guidance to commanders charged with making decisions concerning radiation risk. Chapter 7 lays out the scientific issues in planning and conducting follow-up activities.

Finally, in Chapter 8, the committee presents its main recommendations. The committee points out that while Army interest in ionizing radiation provided the impetus for this report, the issues that the committee raises in that context are in large part applicable to considerations of any potentially harmful exposure during military operations.

This chapter (Chapter 1), having presented the background to the committee's endeavor and the layout of this final report, proceeds with a section on ethics that introduces themes upon which the committee draws throughout this report. These themes have been considered in the scholarly literature and in the immediate context of specific issues (for example, ACHRE, 1995; Beauchamp and Childress, 1994; National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research, 1979).

ETHICS

There is a general ethical principle that one should not put individuals at risk of harm. Exceptions to this principle require justification.

There are standard, not mutually exclusive, ways of looking at how to ethically justify placing some at risk for the benefit of others: consent and role-related responsibility. The most obvious appeal is *consent.* In many circumstances it is considered ethically justifiable to place individuals at risk of harm for the benefit of others if they consent to that imposition-that is, if they assume the risk rather than having it imposed on them. However, for consent to justify

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the imposition of risk, the consent itself must be ethically valid. It must be based on an adequate understanding of the nature and implications of the risk, and the person must be free to refuse.

Another way of thinking about risk focuses on *role responsibility*. There are certain roles, like soldiering, that carry with them an obligation to bear risk for the benefit of others. To give a nonmilitary example, inherent in the physician role is the assumption of the risk of contracting an infectious disease in the course of caring for patients. Although a physician may take appropriate preventive precautions, it generally is not an acceptable response for a physician to refuse care. There are both voluntary and involuntary assumptions of roles; it does not necessarily follow that because a role was not voluntarily assumed that it does not carry with it some socially acceptable and morally justifiable risk. For example, whether they enlist or are conscripted, all soldiers assume the role-related risks of military service.

Justifications of consent and role responsibility do not exhaust the ethical considerations associated with the imposition of risk. Several other ethical conditions must be satisfied.

There must be an analysis that supports, if not demonstrates, that no more risk is being imposed or placed on the individual than is necessary to achieve the goal. This is the optimization principle of radiation protection, implemented by ALARA—as low as reasonably achievable—procedures. In addition, the ethical duty to minimize risk includes taking steps to minimize the likelihood that the risk will materialize into harm. In this context, the duty includes the responsibility for appropriate follow-up of exposed and potentially exposed individuals. Dosimetry, recordkeeping, and medical monitoring all support postexposure efforts to minimize harm.

The goal of the enterprise must itself be ethically acceptable. In this context, it is the military mission that must be ethically acceptable, although this judgment cannot be up to the individual military person once an operational situation is underway. Moreover, the military mission must in some meaningful sense be more ethically significant than the violation of or deviation from the general moral principle of not imposing harm on others.

There is also the duty to treat with respect the persons being placed at risk. Several considerations fall under this obligation, one of which is *disclosure* of the risk to the person both before and after the exposure. Failure to disclose the imposition of risk is to treat those exposed as if they were objects rather than persons of moral worth and dignity. Prior disclosure of information enables the person to exercise judgments that aid in protecting the individual against exposure. Postexposure provision of information can alert the person to recognize possible early symptoms and seek medical attention. Another consideration relating to the ethical obligation to respect persons is to respect the *privacy* of the person who has been put at risk of harm. Privacy enables the individuals to have control over access to information about their exposure and the uses that others might make of this information.

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Another concept related to thinking in moral terms about placing individuals at risk for the benefit of others is *remedy*. One provides a remedy, which is generally financial compensation but which could be some other action such as hazard pay or access to medical care, for the simple assumption of the risk. Alternatively, the Department of Veterans Affairs limits the provision of a remedy only to circumstances in which the risk materializes into harm. It provides various types of compensation to soldiers who have been at risk and become disabled to some degree. Although the committee addresses only medical harm (physical and psychological) in this report, it recognizes there are other kinds of harm that the government might want to explore.

Finally, there is the set of considerations having to do with *justice*. Who is to be exposed? If the answer to this question includes any groups or individuals who are particularly vulnerable, particularly open to exploitation, or particularly burdened by preexisting harms or risks, then the mission may not be just. Determination of what is just in the distribution of risk often includes the need to make morally problematic trade-offs. Consider, for example, having to decide between a radiation exposure that carries a risk of radiation-related cancer that might become apparent and be diagnosed 20 years later and an imminent risk of injury or death from a non-radiation-related military threat. How should one weigh deaths or injuries that may occur in the present against deaths or illness that may occur in the future? Does it matter morally if, in choosing the nonradiation threat, the harm would befall only a small number of identifiable soldiers, while, if the choice were radiation exposure, it cannot be known at the time who among those exposed will subsequently suffer the harm?

Military Context

This ethical framework applies generally and is as applicable in a military as in a civilian context. Features of the military context further increase the ethical burdens on commanders and the military in relation to soldiers. Commanders have much more authority over soldiers than civilian employers have over their employees. Members of the military are obligated to follow all lawful orders, even those that put them at risk of death or disability.* Even in the context of "volunteering" for high-risk duties, the chain of command and the culture of the military do not allow free choice. Moreover, unlike civilians, military personnel

* In combat situations, for example, military personnel may be required to take investigational drugs without informed consent if a determination is made that the drug is necessary to accomplish the military mission and consent is "not feasible." This was done for the first time in the Gulf War (Annas, 1998). In 1998, Congress limited the authority to waive the consent requirement for investigational drugs to the President, and in addition required the President to make specific findings before authorizing a consent waiver and notify specific members of Congress of his decision in writing (USC, 1998).

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cannot sue their employer (the government) for compensation or remedy for injuries due to negligence.

Because health care in the military does not involve the range of choice of physician or medical facility exercised by many other groups of individuals, the handling of medical records presents another ethical concern. Although discharged military personnel have a right to compensation for service-related injuries, such compensation is difficult to obtain in the absence of adequate dosimetry records. Medical and related records (including radiation exposure information) are vital to ensuring that ethical consideration of possible radiation injury has been taken into account in addressing the military objective.

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2

Fundamentals of Radiation Safety and Protection

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

RADIATION PHYSICS

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

When these forms of radiation strike atoms of any material, they may have enough energy to eject electrons, thus resulting in the creation of charged ions. This process, called *ionization,* can result in the breaking of the 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 chemicals, such as deoxyribonucleic acid (DNA), the genetic material that is located in the chromosomes within the cell nucleus.

Alpha radiation colliding with atoms gives up its 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 emitted by radioactive materials are not likely to be harmful when striking the outside of a human body

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

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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, their emissions 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-emitting radionuclides may be encountered in contamination created by intentional or accidental dispersion of nuclear weapon-source materials (e.g., plutonium-239) or as a result of a nuclear detonation. Alpha-emitting radionuclides, such as radium in soil and radon in air, are also naturally occurring sources of radiation and contribute to normal background levels.

In comparison to alpha radiation, fast-moving electrons, which are known as beta particles, have much smaller mass and electric charge, are more deeply penetrating, and dissipate their energy over a larger volume of tissue. Even high-energy beta particles, however, will transfer most of their energy and come to a stop within about 1 centimeter of plastic, 1 to 2 centimeters of tissue, or 4 to 5 meters of air. Therefore, beta particles that strike 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-emitting radionuclides are of most concern after they have entered the body and can transfer their energy to nearby cells of internal organs. Beta-emitting radionuclides may be found in contamination consisting of fission products from a nuclear detonation or resulting from the dispersion of nuclear reactor waste or radiotherapy sources (e.g., cesium- 137 and cobalt-60).

Gamma rays and x rays, which are emitted from radionuclides as well as produced by machines, are the most penetrating forms of ionizing radiation and consist of electromagnetic energy. While randomly colliding with electrons in the body along a scattered path length, gamma rays may give up all or part of their energy in tissue or, although it is unlikely, 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, whereas x rays are most commonly encountered in the use of radiation-producing equipment used in medical applications (including those in combat medical facilities).

RADIATION UNITS AND MEASUREMENTS

Radiation Units

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

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($C\ kg^{-1}$) of air, formerly* 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., I R = 1 rad).

Although 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, expressed in terms of their intake, is related to their concentrations 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; the gray is equivalent to the absorption of one Joule of energy per kilogram. One gray equals 100 rad; 1 milligray (mGy) equals 100 millirad (mrad). However, the amount of energy deposited in tissue does not account for differences in the biological effects of different radiation types.

Equivalent Dose

The dosimetric quantity that accounts for the differences in biological effectiveness of various types of radiation and that allows doses from different radiations to be combined, through expressing their health effects on a common basis, is called the *equivalent dose.* It is calculated by multiplying the absorbed dose by the appropriate radiation weighting factor, "w_R" (ICRP, 1991a). For example, the factor for alpha particles is 20 and that for gamma and beta radiation is 1, indicating that it requires the absorption of about 20 times more energy from gamma or beta radiation than alpha radiation to cause a given biological effect. These weighting factors are approximate and the true value for a given type of radiation, radiation effect, or specific population can vary by up to an order of magnitude. The unit of equivalent dose is the sievert (Sv), formerly the rem. One sievert equals 100 rem; 1 millisievert (mSv) equals 100 millirem (mrem).

* Common usage before the 1960 Conférence Générale des Poids et Measures at which the International System of Units (SI) was adopted.

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Just as different radiation types are more or less effective in damaging tissue, different tissue types have various sensitivities to that damage. For a given equivalent dose of radiation, the more sensitive tissues show a larger increase in cancer and leukemia rates than do less sensitive tissues. For radiation protection purposes, the International Commission on Radiological Protection (ICRP) has developed weighting factors for tissues (called "w_T") that describe the relative sensitivities of different tissues to long-term effects. Tissue weighting factors facilitate the combination of doses to allow a quantitative comparison of the long-term risk from partial body exposure to that from total body exposure. Tissues that are very sensitive to long-term effects from radiation have high weighting factors (e.g., bone marrow w_T= 0.12), whereas less sensitive tissues have lower weighting factors (e.g., skin w_T = 0.01).

The *effective dose* (that is, the dose to the whole body that represents an equivalent risk) is estimated by multiplying the equivalent dose in each tissue type by its corresponding tissue weighting factor and summing these weighted equivalent tissue doses. 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 sievert or millisievert. Dose limits set for occupational exposures are expressed as effective dose and include the sum of the 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

Dose	Correction Applied	International Unit[a]	Traditional Unit[b]
Absorbed dose	No correction	Gy or mGy	rad or mrad
Equivalent dose	Modification of absorbed dose, using w_R,[c] to account for differences in radiation type (alpha, beta, gamma, etc.)	Sv or mSv	rem or mrem
Effective dose	Same modification as above, coupled with adjustment for the sensitivity of various tissues, using w_T[d]	Sv or mSv	rem or mrem

[a] The International System of Units is abbreviated SI for the French *Système Internationale.*
[b] 1 Gy = 100 rad and I Sv = 100 rem.
[c] w_R is the ICRP radiation weighting factor.
[d] w_T is the ICRP tissue weighting factor (ICRP, 1991a).

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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-radiation detection, for example, will not give accurate information for the other types of radiation. A radiation safety program specifies the appropriate equipment to be used to estimate an individual's level of exposure to radiation from external sources.

For the direct measurement of 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 indicate only 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 (GM) or sodium iodide detectors. These meters are used to find contamination, although the GM detector may be calibrated to provide exposure readings. The conversion must take into account the efficiency of the probe and a number of other factors.

An ion chamber is designed to measure exposure, that is, ionization in air due to gamma rays (in coulombs per kilogram or roentgen). 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 opened, the instrument will respond to beta, as well as gamma, radiation. However, these instruments are not usually calibrated for beta radiation, so the instrument reading may not be accurate for them.

A GM detector is primarily designed to measure the number of alpha, beta, or gamma rays that emanate from a source and strike 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 coulombs per kilogram (or roentgen).

The devices briefly discussed 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. Through the use of a filter or by

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impaction on a collection plate, this device removes solid radioactive particles from the air and concentrates them sufficiently to be measured by a detector similar to those discussed above. Such measurements, however, must frequently be made in the laboratory.

Determination of internal doses resulting from exposures to inhaled or ingested radionuclides is much more difficult and time-consuming than determining external dose. It requires measurements of levels of air (or water or food) contamination, identification of significant radionuclides, measurement of the amounts excreted by the exposed person, such as in the urine and feces, 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, for example, through use of a whole-body counter. Under battlefield conditions, rough measurements of environmental contamination can be made as a basis for estimating both internal and external doses. If calibration factors are available for open-window ion chambers and GM counters, those instruments may be used to obtain 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, the committee provides a perspective for considering 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 radiation from radioactive elements and technology-enhanced (often referred to as "man-made") 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, 1987a). A major portion of this arises through internal exposures, namely, 2 mSv (0.20 rem) from airborne radon and its decay products, and 0.39 mSv (0.039 rem) from naturally occurring radionuclides in the human body. The remainder comes from external sources, namely, 0.28 mSv (0.028 rem) from cosmic radiation and an equal amount from naturally occurring radioactive materials in 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 effective dose for natural background radiation from cosmic rays and terrestrial sources in Denver, Colorado, is 50 percent higher (NCRP, 1987b) than the national average.

In addition to the doses from background radiation, some soldiers are engaged in duties in which they are at risk of exposure to higher levels of ionizing

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radiation. Examples of such duties include repairing and maintaining radioactive commodities (e.g., ammunition containing depleted uranium and luminescent sights containing tritium), flying at high altitudes, and administering radiation for medical diagnosis and therapy. 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 the approximately 400,000 service members who either were in the occupation forces near Nagasaki and Hiroshima, Japan, at the close of World War II or participated in the aboveground nuclear test program conducted between 1945 and 1962. Of the 202,000 military personnel at test sites (VA, 1997), about 1,750 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 estimated doses that exceed the more conservative annual occupational limit—20 mSv (2 rem)—recommended by the International Commission on Radiological Protection (ICRP, 1991a). A total of 0.07 percent of the doses exceeded 100 mSv (10 rem); 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 Radiation[a]

Dose Range (mSv)	No. of Personnel Receiving the Dose	Percentage of Total
0	13,187	82.7
0-1	2,461	15.4
1-5	269	
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 DOSE REDUCTION

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

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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 the 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). When dealing with planar sources such as radioactive fallout on the ground, the decrease in dose with distance is much less.

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 radiation can be stopped by a piece of paper. Beta radiation can be blocked by about a centimeter of plastic. Clothing and the outer layers of skin cells provide some protection from beta radiation outside the body. Gamma radiation, 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. Increasing the rate of elimination is very specific to the radionuclide and its chemical form. It can be done for some radionuclides (e.g., tritium and iodine) by increasing the amount of fluids entering the body. For other radionuclides (e.g., plutonium) potentially toxic cheating agents can be considered.

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.

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 in cellular water a free radical that can subsequently damage DNA. Two-thirds of the tissue damage created by radiation is caused by these indirect processes.

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Complete and accurate biological repair of such DNA damage is a normal process that occurs millions of times daily. However, 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 or 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. Studies with animals 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 (Bair, 1997; 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. However, some tissues, such as lymph nodes, which can accumulate radionuclides to high concentrations and which can receive high radiation doses, are much less susceptible to radiation-caused cancers than other tissues, 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, except if the radiation is scattered. Most acute effects of radiation are due to cell killing; these are described as *deterministic* effects. Long-term effects are usually due to gene mutations in exposed cells; this type of effect, such as radiation-induced cancer, is termed a *stochastic* effect.

Deterministic Effects

The most important cause of deterministic effects is irreparable radiation-induced DNA damage resulting in premature cell death or the inability of the cell to divide. If cells are damaged faster than they can be replaced or repaired, the exposed person's health may be adversely affected. If this damage versus repair differential is present, clinical signs will be detectable and symptoms may develop early in the postexposure period (within about 2 months).

In contrast to stochastic effects, deterministic effects do increase in severity with dose and have a practical threshold dose below which they are not observed. 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 centime

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ters of tissue to interact with DNA in cells deep within the body. Radiation from high-energy beta-emitting radionuclides, 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 the outer layer. These exposures have the potential to cause local skin injuries and effects according to the penetrating range. Such manifestations of acute radiation-induced health effects can occur alone, in combination with each other, and with non-radiation-induced trauma, including thermal burns, or other serious medical conditions. Combined injuries of these types tend to be synergistic, that is, the combination can have more of an effect on the health of the exposed person than the sum of the effects of the individual contributors.

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

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 formation process	Bone marrow	500	ICRP, 1984
Reversible skin effects (e.g., reddening)	Skin	1,000-2,000	UNSCEAR, 1982
Permanent sterility	Ovary	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

If the dose is received instantaneously or within a short time, the threshold for early radiation effects may be rapidly reached or exceeded, resulting in acute effects. This can occur in the event that a high dose from a source outside the body (e.g., nuclear weapon detonation) is received 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. For a given total dose, the effects of protracted or fractionated doses are less than those of acute doses for two reasons: (a) the numbers of cells being killed by the radiation over time will be less than the numbers of new cells being produced in the body's tissue systems during the same period; and (b) because repair of radiation injury occurs within most cells. Doses of radiation can be accumulated over long periods as the result of repeated exposures to radiation outside the body, and when long-lived radionuclides (as opposed to short-lived [rapidly decaying] radionuclides)

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are deposited in body tissues. Although alpha- and beta-emitting radionuclides can cause early radiation effects in the tissues in which they are deposited, the likelihood that they will cause 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.

Another key factor in the body's response to ionizing radiation is the relative sensitivity to radiation of the various cell types that make up 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 the acute effects of radiation. The more highly differentiated cells (e.g., muscle and nerve cells) are less vulnerable to acute injury as a result of 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 responses 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 should 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 in excess of 50 mSv (5 rem) to the embryo or fetus is associated with an increased risk (relative to the risk for the nonexposed embryo or fetus) 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; NCRP, 1998).

Stochastic Effects

Incomplete repair or misrepair of radiation-induced DNA damage increases the risk of tumors and heritable 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 types of late effects that can occur depend on the types of cells affected.

Radiation-induced gene mutations in some types of cells (somatic cells) 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 influence the pro

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gression of every transformed cell to a malignant focus for cancer or leukemia development. Such factors include the age of the individual at the time of exposure, sex, 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 that such effects will occur 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 to 5 years for radiation-induced leukemias and 10 years for most solid cancers.

Although 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 the thyroid gland and female breast tissue, several types of cancer (e.g., lung, thyroid gland, and female breast cancer), 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 of individuals who have had medical diagnostic or treatment exposures, and some occupationally exposed individuals. Although many people were exposed to significant radiation doses after the accident at the Chernobyl nuclear power plant in the former Soviet Union, the follow-up for these individuals is not yet sufficiently long to allow these data to be used to predict the incidence of various cancers induced by radiation exposure. Evidence of the radionuclide intakes that cause harmful effects in populations is relatively scarce and is limited to radium-dial painters, patients treated with radium or thorotrast, uranium and other miners exposed to radon, Pacific Islanders exposed to radioiodine fallout after nuclear weapons tests, and to individuals downwind of Chernobyl who were exposed to radioiodine. Health effects that can definitely be attributed to radionuclide intakes have not been identified in nuclear or medical workers.

The most useful data have been obtained from the atomic bomb survivors in Japan (Pierce et al., 1996; Preston et al., 1994; Thompson et al., 1994), and patients with ankylosing spondylitis or with certain tumors, including carcinoma of the cervix, who received radiation therapy (NRC, 1990). Data from a number of other studies have been used, including those involving patients receiving fluoroscopy for tuberculosis and in utero diagnostic radiation exposure. This material has been collated in a number of reports, including a series of reports on the biologic effects of ionizing radiation (BEIR) beginning in 1972, the latest being BEIR VI, published in 1998 by the National Research Council (National Research Council, 1998). Important analyses of Japanese atomic bomb survivor data have been reported in, among others, four publications of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 1977, 1982, 1988, 1994),

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as well as the 1990 Recommendations of the International Commission on Radiological Protection (ICRP, 1991a).

ASSESSMENT OF RADIOGENIC TUMOR RISK

Risk Factors

The risks associated with radiation exposure in the range of 50 to 700 mSv (5 to 70 rem) are confined primarily to the risk of an increased incidence of malignant diseases, including many solid tumors and leukemias. The exposure and disease incidence and mortality data have been analyzed in depth and have been converted to various estimates of risk that are generally based on a model calculation that predicts the number of cancer deaths per 10,000 persons per sievert of exposure. A number of models have been used to project from baseline data for the atomic bomb survivors to the risk of excess deaths. For most organ sites, the currently preferred model is the multiplicative one, in which the relative risk resulting from the exposure to two risk factors is the product—rather than the sum—of the relative risk for the two factors taken separately (National Research Council, 1990). For a working-age population (25 to 64 years of age), this model predicts 700 to 800 excess fatal cancers over the lifetime of 10,000 persons externally exposed acutely to I Sv (1 Gy of whole-body low linear energy transfer [LET] radiation) (UNSCEAR, 1988; Upton, 1991).

Predictions of risk of leukemia and nonleukemia derived for BEIR V (National Research Council, 1990) are presented in Table 2-4 for men and women as well as for acute and chronic exposure.

Some information on the shortening of life span from causes other than cancer or leukemia as a result of whole-body radiation exposure is available. However, the information is not sufficient for quantification of this risk (Shimizu et al., 1992).

Dose Range Covered by the Guidelines in This Report

Risks estimated by a commander are based upon estimated doses for that mission; however, the commander should be aware than an individual's radiogenic cancer risk is a function of his or her cumulative radiation doses including those incurred prior to an anticipated mission. As expressed later, in Chapter 5, the committee has taken the dose categories listed in the Allied Command Europe table to be cumulative doses (NATO, 1996).

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TABLE 2-4. Excess Cancer Mortality Estimates: Lifetime Risks Per 100,000 Exposed Persons

	Continuous Lifetime Exposure of 1 mSv y^{-1} (deaths per 100,000 population)				Instantaneous Exposure of 0.1 Sv(deaths per 100,000 population)			
Type of Cancer	Males No.	% Excess	Females No.	% Excess	Males No.	% Excess	Females No.	% Excess
Leukemia	70	8.9	60	8.6	110	15.0	80	14.0
Nonleukemia	450	2.3	540	3.2	660	3.3	730	4.7
Total	520	2.5	600	3.4	770	3.7	810	5.0

SOURCE: Adapted from BEIR V (National Research Council. 1990), Table 4-2. p. 172.

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Modification of Risk

A number of factors have been shown to influence the risk of radiation-induced malignancies.

Age

The risk of radiation-induced leukemia is highest among the youngest exposed, including those exposed in utero, infants, and young children, and decreases to a constant risk by age 15 years. The risk of radiation-induced thyroid cancer is higher among infants and children than among individuals exposed at older ages. Breast cancer, although observed later in life, is more common when the individuals are exposed to radiation in childhood or as adolescents; the risk decreases up to the age of menopause, beyond which the risk of radiation-induced breast cancer is not detectable against the rate of spontaneous breast cancer in nonexposed groups (UNSCEAR, 1994). For many other tissues, there are not enough data to establish a relationship between age at exposure and the risk of subsequent malignancies.

Sex

With the exception of leukemias, the overall risk of radiation-induced malignancy is generally considered to be higher for females than for males. These differences are proposed to be the result of hormone-dependent promoting factors and differences in cofactors rather than differences in radiation sensitivity according to sex (ICRP, 1991 a).

Type of Radiation

The biological effects of radiation depend upon the energy transferred to the tissue, and these effects are a function of the type of *linear energy transfer* (LET). LET refers to the amount of energy deposited in a unit of the distance along the track of radiation. The amount of energy deposited into tissue can be measured as a function of this distance. Various types of ionizing radiation are divided into high-LET and low-LET radiation (Mettler and Upton, 1995). For a given absorbed dose, high LET types of radiation, such as neutrons and alpha particles, are more effective than low LET types, such as gamma and x rays, in inducing malignancies.

Dose Rate and Magnitude

Dose rate and dose magnitude have significant effects on malignancy induction, particularly for low LET radiation. It is generally accepted that small repetitive doses or exposures at low doses and low dose rates are associated with a lower

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risk of radiation-induced malignancy than a single large exposure. The exact adjustment for dose rate or small-fraction exposure is not known; however, adjustments in the range of a factor of 2 to 10 have been suggested (National Research Council, 1990; UNSCEAR, 1994). Thus, adjustments for dose rate and exposure magnitude should be considered when estimating risk on the basis of data from the usual tables of single acute exposures. A dose delivered continuously at a low dose rate or in multiple small fractions will be significantly less effective than the same total dose delivered instantaneously.

Tissue

For a certain absorbed dose, the risk of radiation-induced cancer varies by tissue. The comparative susceptibilities of different tissues to radiation-induced cancers can be grouped into high, moderate, low, and very low or absent categories (Mettler and Upton, 1995), as illustrated in Table 2-5.

Ranking by cancer deaths rather than incidence is displayed in a table (Table 2-6) adapted from ICRP Publication 60 (ICRP, 1991a). As calculated by using probability coefficients for fatal cancers, an estimated 5 excess cancer deaths would occur among 10,000 people receiving 0.01 Sv (I rem). The differences by tissue type are evident.

Radiation-induced malignancies occur only in those organs, tissues, or parts of the body that have been irradiated. Risk assessment as a result of internal exposure is much more problematic due to the complexity of estimating the organ dose and its distribution within the tissues, but it must be considered. Some radionuclides are preferentially deposited in specific tissues instead of throughout the body and are associated with the development of specific cancers in those tissues. For example, when radioactive iodine enters the body, it is deposited primarily in the thyroid gland, exposing the thyroid tissue to radiation over a long period. Groups of people exposed to radiation in this way have a higher risk of developing thyroid cancer than unexposed groups.

Heritable and In Utero Effects

On the basis of a review of data for the children and grandchildren of Japanese atomic bomb survivors, there is no significant evidence of an increased incidence of heritable abnormalities following radiation doses. Some heritable abnormalities are probably induced, although the incidence is too low to have ever been directly observed; consequently, they are not a major consideration in the estimates of risk.

The effects of radiation on the fetus and embryo have been observed with exposures in the range of 50 to 700 mSv (5 to 70 rem) during the 8th to 25th week of gestation. Mental retardation and decreased IQ are some of the major effects. In addition, nonspecific teratogenesis, which may be fatal to the fetus, is associated with gestational exposures.

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TABLE 2-5. Comparative Susceptibilities (based on percent increases in background incidence) of Different Tissues to Radiation-Induced Cancer

High
Bone marrow (leukemia other than chronic lymphocytic leukemia)
Breast (female)
Salivary glands
Thyroid (more common in females)
Moderate
Bladder
Colon
Stomach
Liver
Lung
Ovary
Skin
Low
Bone
Brain
Connective tissue
Kidney
Larynx
Nasal sinuses
Very low or absent
Cervix
Chronic lymphatic leukemia
Oral cavity
Esophagus
Melanoma
Prostate
Uterus
Pancreas
Rectum
Gallbladder
Hodgkin's disease
Lymphatic system and myeloma
Testes
Muscle

SOURCE: Table 4-1 in Mettler and Upton, 1995.

Interaction with Other Exposures

In the therapeutic medical setting, there are chemicals that interact with radiation. Some are radioprotective, some have no effect, others have additive ef

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fects, synergistic effects, or effects in-between. However, the effects of chemicals that soldiers might encounter in military operations are largely unknown.

TABLE 2-6. Lifetime Mortality from Specific Fatal Cancer After Exposure to Low Doses at a Low Dose Rate for a Population of All Ages

Tissue or Organ	Fatal Probability Coefficient (10^{-4} Sv^{-1})
Bladder	30
Bone marrow	50
Bone surface	5
Breast	20
Colon	85
Liver	15
Lung	85
Esophagus	30
Ovary	10
Skin	2
Stomach	110
Thyroid	8
Remainder	50
Total	500

SOURCE: Adapted from Table B- 17, 1990 Recommendations of the ICRP, p. 132 (ICRP, 1991a).

How to Apply Risk Factors

Although the risks in Tables 2-4 and 2-5 are by specific dose, risks can be scaled to other doses on the basis of the linear relationship assumption. Scaling down from a 1-Sv (1,000-mSv) dose should be done with some caution, however, because the effects at very low doses remain to be unambiguously defined. For radiation protection purposes, it is assumed, in the absence of data for humans exposed to very low radiation doses, that there is no dose of radiation below which there is no increased cancer risk. Thus, the risk for 100 mSv (10 rem) would be 10 percent of the risk at 1,000 mSv (100 rem). To project incidence rather than mortality, one would divide the excess mortality by the lethality fraction. For example, thyroid cancer has an estimated lethality fraction of 0.1; thus, the cancer incidence would be 10 times the mortality rate. This calculation and interpretation is useful in counseling people as to what the relative risk of the

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incidence of cancer would be after a given exposure to a specific organ. With regard to exposures to military personnel, total individual risk is the cumulative risk from both the current mission and prior radiation exposures while either in the military or in civilian life.

Putting the Risks in Perspective

One can summarize the available data on risk of malignancy induction in a number of ways. For example, for a population of 100 25-year-old males instantaneously exposed to 100 mSv (10 rem), there will be an excess of approximately one fatal cancer. Thus, the excess risk is approximately I percent (I in 100 chances) in addition to the natural rate of fatal cancer in the general population of about 20 percent (20 in 100 chances). If this were chronic exposure, the risk would be half of the above.

In his conclusions in the *Annals of the ICRP,* Upton states, "On the basis of the latest evidence summarized in the reports from UNSCEAR and BEIR V, the task group concludes that the life time excess risk of fatal cancer for a member of the general population exposed to low dose rate whole-body irradiation can be assumed to average approximately 5 per cent per sievert" (Upton, 1991, pp. 26-27).

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3

Standard Practices in Occupational Radiation Protection

In determining whether the guidance from the North Atlantic Treaty Organization embodied in the Allied Command Europe (ACE) Directive adequately follows generally accepted practices of radiation protection, the committee first reviewed standard practice. 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. On the basis of their own needs and the recommendations of these organizations, various federal agencies, such as the U.S. Nuclear Regulatory Commission and the Environmental Protection Agency, have developed and continue to develop specific implementing regulations.

In this section, the committee summarizes current radiation protection philosophy and procedure in the United States. Later, in Chapter 5, this will be a yardstick against which the ACE Directive is compared.

CONTROL PHILOSOPHY

The philosophy of radiation protection and the practices that ensure radiation safety must include social as well as scientific judgments to provide an appropriate standard of protection without unduly limiting military operations. The overall goal of radiation protection, regardless of the specifics of the situation that leads to exposure, is to prevent the occurrence of acute effects (e.g., cataracts, radiation burns, and acute radiation sickness) and to 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

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achieve that aim will vary, depending upon the radiation exposure scenario. The two types of exposure scenarios addressed here are (1) practices (routine and potential) and (2) interventions.

The first of these, a *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, maintaining a nuclear reactor (or nuclear electric generating station), or taking measurements using radioactive sources. These occupationally exposed individuals are trained to appreciate the hazards of radiation, to acknowledge those risks as a condition of employment, and to follow safety precautions to minimize their exposure.

Any practice may involve exposures that do not routinely occur (e.g., accidents). If these have not yet happened, they are called *potential exposures.* Both the probability that such events will happen and the magnitude of the expected radiation doses can be calculated in the planning of 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 radiation exposure (often to other individuals or groups) from specific radiation sources by (ICRP, 1993, p. 1):

1. reducing or removing the existing sources,
2. improving the reliability of the existing sources,
3. modifying pathways,[1] or
4. reducing the number of exposed individuals.

An example of an intervention is the response of the firefighters who fought to control the fire during 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. 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 the level of radiation exposure. The firefighters who responded after the accident were operating under different rules and exposure criteria: those intended for an intervention situation.

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

- justification,
- optimization/ALARA,[2] and

[1] Pathways are routes by which individuals are exposed to radiation (e.g., contaminated water and foodstuffs or radionuclides that are airborne and carried by the wind).

[2] 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 ex

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- limits or reference levels.

Radiation exposure is generally considered something to be avoided unless it can be adequately justified. As mentioned in Chapter 1, radiation at low doses (less than 50 millisievert [mSv]) has not been observed to have effects in humans. However, because of the uncertainty surrounding the effects of low doses, most radiation protection philosophy presumes that even low doses of radiation 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 (ICRP, 1991 a).

As an example of justification, consider the use of medical x rays. Technicians may receive low doses of radiation and may receive some harm, but the greater good provided to patients by the diagnostic x ray is high; hence, the practice is deemed justified. Justification is essential in developing radiation protection for practices and interventions and is also 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, 1991 a, paragraph I 112(b)).

Finally, even when a practice is justified and has been optimized, there are *limits* above which people should not be routinely exposed. Dose limits, when observed, provide protection against exposure to radiation at levels 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 should not be used. Nor are dose limits applicable in planning for potential exposures. When the potential exposure 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) doses received from natural background radiation. Nor do they apply to patients undergoing medical procedures that involve radiation exposure.

Thus far, the committee has 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 have chosen to accept that exposure and the practice of protection as condi

posed, 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, paragraph 112(b)).

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tions of employment. Members of the general public may also be exposed to radiation sources beyond that from the natural environment (e.g., while waiting in a radiology clinic or a cancer therapy department). Unlike workers who are exposed to radiation as part of their occupations, however, members of the general public do not receive direct compensation in return for their exposure, nor do they formally accept the risks of exposure. Therefore, limits set for exposures are significantly lower for the public. Occupational doses are currently limited (CFR, 1991) to 50 mSv per year, whereas exposures to the general public are limited to 1/50 of that: I mSv per year (approximately the same as the annual background dose from sources excluding radon) (CFR, 1991; NCRP, 1987a). Although both of these limits apply to both males and females, more stringent occupational exposure limits apply to an embryo or fetus during the period of gestation. The exposure limit for embryos and fetuses during the 9-month period of gestation is 5 mSv, which is 10 times lower than the usual limit for workers for 1 year (50 mSv).[3]

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 risk of radiation-induced cancer, nor does going above the limit give certainty to future cancer development. 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).

Interventions that limit damage after a nuclear accident (urgent actions) present their own set of problems (ICRP, 1991b). People who are in the immediate vicinity can be exposed to radiation levels that can be estimated only 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 large populations from being exposed to radiation. 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, adherence to dose limits is 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, the effective dose should not exceed 500 mSv and the equivalent dose to the skin should be limited to 5,000 mSv. Also, ICRP (1991b) and the Environmental Protection Agency (EPA, 1991) have recommended intervention levels for sheltering and evacuation, contamination levels for foodstuffs, and procedures for thyroid protection.

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, principles of justifi

[3] This exposure limit applies only to the embryo or fetus of a pregnant woman who has acknowledged (declared) her pregnancy to her employer. See the *Code of Federal Regulations (CFR,* 1991).

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cation and at least crude optimization are applied (ICRP, 1991b). ICRP also recommends that doses be kept within occupational limits, if possible.

Finally, once the accident and radiation exposure are under control, a recovery period begins. During this recovery period 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 unacceptably inefficient to go through the justification and optimization processes every time that a recurring situation arises. 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 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 and 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 different circumstances of radiation exposure into perspective.

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

RADIATION SAFETY TRAINING FOR OCCUPATIONAL EXPOSURES

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 with risks from 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.

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TABLE 3-1. Examples of Typical Radiation Doses and Dose Limits or Reference Levels

Description of Level	Effective Dose (mSv)	Reference
Annual background dose to a person living in the United States, excluding radon	1	NCRP, 1987a
Typical effective dose from a CT scan	1	NCRP, 1987a
Annual limit on exposure of members of the general public	1	ICRP, 1991 a
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 versus 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 life span	70	NCRP, 1987a
Limit for protecting valuable property	100	EPA, 1991
Total background radiation, including radon, over a 70-year life span	210	NCRP, 1987a
Limit for saving a life	250	EPA, 1991
Limit for volunteers saving a life	>250	EPA, 1991
Threshold for deterministic effects* (e.g., bone marrow depression)	500	ICRP, 1984
Career dose limit for radiation workers	1,000	ICRP, 1991 a
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

* That is, not cancer or hereditary effects.

Requirements of the Nuclear Regulatory Commission

The U.S. Nuclear Regulatory Commission is an independent federal agency with the overall mission of protecting the public health and safety in the use of nuclear materials. It is responsible for the licensure and regulation of various entities-such as reactors, disposal sites, and research facilities (Nuclear Regu

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latory Commission, 1998). Nuclear Regulatory Commission Regulatory Guide 8.29, "Instruction Concerning Risks from Occupational Radiation Exposure," states that all individuals who in the course of their employment are likely to receive an occupational dose in excess of I mSv (100 millirem [mrem]) in a year are required to be instructed in the health protection issues associated with exposure to radioactive materials or radiation (Nuclear Regulatory Commission, 1981). This regulatory guide, which supports Title 10 requirements, describes information that should be provided to workers by licensees about health risks from occupational exposure. It requires that Nuclear Regulatory Commission licensees use procedures and engineering controls to the extent practicable to achieve occupational doses that are ALARA.

Radiation protection training for workers who are occupationally exposed to ionizing radiation is an essential component of any program designed to ensure compliance with Nuclear Regulatory Commission regulations. The Nuclear Regulatory Commission material was written with the belief that a clear understanding of what is presently known about the biological risks associated with exposure to radiation would result in more effective radiation protection training and therefore less unnecessary exposure. The employer should make available to occupationally exposed persons relevant information on radiation risks to enable them to make informed decisions regarding the acceptance of these risks. It is intended that workers who receive this instruction will develop respect for the risks involved rather than excessive fear or indifference.

The regulations state that instruction should be given prior to occupational exposure and periodically thereafter. The extent of this instruction should be commensurate with the radiological risks present in the workplace. The instruction should be presented orally, in printed form, or using any other effective communications media. Individuals should be given an opportunity to discuss the information and to ask questions. Testing is recommended, and each trainee should acknowledge in writing that the instruction has been received and understood.

The 17-page regulatory guide presents instruction in the form of question and answer segments. Some of the questions are as follows (Nuclear Regulatory Commission, 1981, pp. 4-14):

1. What is meant by health risk?
2. What are the possible health effects of exposure to radiation'?
3. What is meant by early effects and delayed or late effects?
4. What is the difference between acute and chronic radiation dose?
5. What is meant by external and internal exposure?
6. How does radiation cause cancer?
7. Who developed radiation risk estimates?
8. What are the estimates of the risk of fatal cancer from radiation exposure?
9. If I receive a radiation dose that is within occupational limits, will it cause me to get cancer?
10. How can we compare the risk of cancer from radiation to other kinds of health risks?

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11. What are the health risks from radiation exposure to the embryo/ fetus?
12. Can a worker become sterile or impotent from normal occupational radiation exposure?
13. What are the NRC [Nuclear Regulatory Commission] occupational dose limits?
14. What is meant by ALARA?
15. What are background radiation exposures?
16. What are the typical radiation doses received by workers?
17. How do I know how much my occupational dose (exposure) is?
18. What happens if a worker exceeds the annual dose limit?
19. What is meant by a "planned special exposure"?
20. Why do some facilities establish administrative control levels that are below the NRC [Nuclear Regulatory Commission] limits?
21. Why aren't medical exposures considered as part of a worker's allowed dose?
22. How should radiation risks be considered in an emergency?
23. How were radiation dose limits established?
24. Does the NRC [Nuclear Regulatory Commission] plan to reduce the regulatory limits?
25. What are the options if a worker decides that the risks associated with occupational radiation exposure are too high?
26. Where can one get additional information on radiation risk?

Ideally, at the completion of training, workers will be sufficiently prepared to make appropriate common-sense judgments on radiation safety for their own protection. For this purpose, training should be as site specific and as application specific as possible. The ever increasing challenge today is how to present training that effectively accomplishes these purposes in the least amount of time. The Nuclear Regulatory Commission offers no specific guidance on the length of time required for the training of workers.

Part 19.12 of Title 10 of the Code of Federal Regulations provides the following guidance on the content of training (CFR, 1998a, p. 277):

(a) All individuals who in the course of employment are likely to receive in a year an occupational dose in excess of 100 mrem (1 mSv) shall be-

(1) Kept informed of the storage, transfer, or use of radiation and/or radioactive material;

(2) Instructed in the health protection problems associated with exposure to radiation and/or radioactive material, in precautions or procedures to minimize exposure, and in the purposes and functions of protective devices employed;

(3) Instructed in, and required to observe, to the extent within the workers' control, the applicable provisions of Commission regulations and licenses for the protection of personnel from exposure to radiation and/or radioactive material;

(4) Instructed of their responsibility to report promptly to the licensee any condition which may lead to or cause a violation of Commission regulations and licenses or unnecessary exposure to radiation and/or radioactive material;

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(5) Instructed in the appropriate response to warnings made in the event of any unusual occurrence or malfunction that may involve exposure to radiation and/or radioactive material; and

(6) Advised as to the radiation exposure reports which workers may request pursuant to Sec. 19.13.

(b) In determining those individuals subject to the requirements of paragraph (a) of this section, licensees must take into consideration assigned activities during normal and abnormal situations involving exposure to radiation and/or radioactive material which can reasonably be expected to occur during the life of a licensed facility. The extent of these instructions must be commensurate with potential radiological health protection problems present in the work place.

Risk Communication-An Important Function in Decisions for Radiation Safety

Managers are trained to understand that most decisions are made with an absence of adequate data. If data were sufficient, the objective balancing of the decision would be clear (leaving only the influence of personal and societal values to make the choice complicated). Decisions for radiation safety are most always made with insufficient data. To account for large uncertainties in the knowledge of radiation and its effects, one must make many assumptions. Evaluations of radiation risks are therefore very difficult to make—even for trained specialists in radiation safety. The process can lead to extensive debate, especially when the evaluation concerns low radiation doses. Yet, one expects radiation workers to make decisions on the basis of an informed understanding.

Central to the concept of informed understanding is the recognition that decisions regarding radiation safety involve many uncertainties. Such uncertainties arise from:

- limitations associated with data regarding the radiation source, including its type and form, concentration, containment, and environmental transport;
- limitations associated with radiation measurement, including improper application, calibration, and operation and reading of instrumentation-all of which are components of quality assurance;
- limitations arising from inappropriate interpretation of instrument readings and inappropriate use of statistical techniques;
- limitations associated with data regarding the mode of radiation exposure (e.g., internal versus external exposure and the conditions in which exposure occurred);
- limitations regarding knowledge of the quantification of radiation energy deposition in the human body, including organ dose, quality factor, dose rate, and appropriate dose measure (e.g., gray or sievert);

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- limitations regarding knowledge of the effects of radiation, including the dose-response relationship; stochastic and deterministic effects; latent period; and the modifying effects of age, sex, and medical history;
- limitations associated with the ability to communicate and understand the risks associated with radiation (e.g., jargon, commonly held perceptions and mental images, fears, and cultural and language barriers);
- limitations regarding the understanding of how best to weigh the benefits and competing risks associated with radiation exposure (justification and optimization);
- limitations imposed by ill-defined ethical, legal, and liability issues associated with radiation exposure (e.g., current and future obligations, the interpretation of future risks, and concerns for mistakes); and
- limitations due to the uncertainties involved in the choice of activity objectives that may result in radiation exposure risks.

Because of the complexity of radiation risk analyses, resulting in part from the uncertainties outlined above, it is customary to make many simplifying assumptions. International scientific organizations and regulatory authorities regularly perform risk analyses and develop guidelines for radiation safety practices. In any specific circumstance, a manager may make a decision regarding radiation safety by comparing the exposures or doses with the guidelines. However, information with which to estimate the radiation dose, especially for estimating dose from internally deposited radionuclides, is not always readily available. The processes of risk perception and risk communication are complex and are the subjects of a substantial body of literature (for example, Covello, 1991; Fischhoff et al., 1984; Morgan et al., 1992; National Research Council, 1989, 1996; Slovic, 1996; Wilson, 1979). In this report, the committee provides only a brief overview.

Training and Radiation Risk Perceptions

Individuals assess risk in disparate ways on the basis of their past experiences. Some individuals would take a I in 100,000 risk, thinking that the adverse event would not happen to them. Others would not take that risk, expecting the event's occurrence. Such decisions assume cause and effect for radiation exposure without analysis of any of the uncertainties defined above.

Workers come to radiation safety training with preexisting ideas and impressions about radiation risks. These come from previous training, the attitudes of coworkers, the news media, and advice from friends and relatives. Workers filter the information presented in radiation safety training through these perceptions. Whether they hear and subsequently accept the information presented in training depends, in part, on whether the training agrees with their previous ideas. When trainers present information that is different from preconceived notions, trainees may not only be unreceptive to the new information but may also

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be suspicious or doubtful of the training and therefore react with resistance or hostility. Radiation safety training therefore is more effective if risk perceptions are addressed at the beginning of a training session.

With radiation safety training, workers may change their impressions but only to the extent that the instructor helps them create new images to replace the old ones. To change impressions, trainees must see evidence that is stronger than the basis for their impressions. This means that radiation safety training must not be presented as abstract concepts but by demonstration, which allows the students to confirm new information with their own eyes and ears.

Workers or students should be invited to compare the instructor's data or information with their own experience or expectations. The challenge for an instructor is to provide new experiences and data to revise old images. This can be accomplished by inviting the class to challenge the radiation concepts that the instructor provides. This allows the instructor the opportunity to prove such concepts through the use of demonstrations or anecdotes with which the class can identify. As students absorb the proofs, they may change their images or impressions of radiation. New images lead to changes in risk perceptions, becoming a foundation for decisions based on informed understanding.

RECORDS AND RECORDKEEPING

Radiation safety programs are designed and used to protect persons against ionizing radiation exposures that are unnecessary in the workplace or that are considered unacceptable to the general public. Protection limits are used and further efforts are made to keep exposures as low as reasonably achievable. The health objectives of a radiation safety program are to prevent and avoid exposures that can result in severe acute health effects and to minimize exposures that may increase the risk of developing cancer and other radiation-related health effects. To meet these objectives, the recording and maintenance of all relevant exposure information is essential (ICRP, 1991 a) and serves to (NCRP, 1992)

- aid in the protection of individuals;
- evaluate the effectiveness of the 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.

As an example of the scope of information contained in radiological exposure records, the International Atomic Energy Agency (IAEA, 1996) requires that occupational exposure records be maintained for each worker. These records should include (IAEA, 1996, Appendix I):

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(a) information on the general nature of the work involving occupational exposure;
(b) information on doses, exposures and intakes at or above the relevant recording levels and the data upon which the dose assessments have been based;
(c) when a worker is or has been occupationally exposed while in the employ of more than one employer, information on the dates of employment with each employer and the doses, exposures and intakes in each such employment; and
(d) records of any doses, exposures or intakes due to emergency interventions or accidents, which shall be distinguished from doses, exposures or intakes during normal work and which shall include references to reports of any relevant investigations.

Workers are provided access to information in their own exposure record; however, due care and attention must be given to the maintenance of the appropriate confidentiality of the records.

Exposure records are to be preserved not only during the worker's working life but also at least until the worker attains or would have attained the age of 75 years and for not less than 30 years after the termination of the work involving occupational exposure.

The U.S. Department of Energy requires of its operations a records management program that includes the following (DOE, 1994, p. 7-3):

a. Radiological Policy Statements
b. Radiological Control Procedures
c. Individual Radiological Doses
d. Internal and External Dosimetry Policies and Procedures (including Bases Documents)
e. Personnel Training (course records and individual records)
f. As Low as Reasonably Achievable (ALARA) Records
g. Radiological Instrumentation Test, Repair and Calibration Records
h. Radiological Surveys
i. Area Monitoring Dosimetry Results
j. Radiological Work Permits
k. Radiological Performance Indicators and Assessments
l. Radiological Safety Analysis and Evaluation Reports
m. Quality Assurance Records
n. Radiological Incident and Occurrence Reports (and Critique Reports, if applicable)
o. Accountability Records for Sealed Radioactive Sources
p. Records for Release of Material to Controlled Areas
q. Reports of Loss of Radioactive Material.

The following are among the commonly kept records on radiation exposures.

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Program documents record any authorizations and accreditations that allow or regulate the exposure of individuals to radiation (e.g., radioactive material licenses from the U.S. Nuclear Regulatory Commission or U.S. Department of Defense 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, and documentation of efforts to keep exposures ALARA.

Individual records document relevant data on each individual exposed to radiation as part of his or her occupational duties. These include items such as exposure categories for individuals (e.g., managers who receive minimal radiation doses versus technicians who receive larger doses). Also of interest are individual dose records (internal and external), training records, and details of any overexposures, as well as age, sex, 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. This allows the calculation of accumulated internal dose and, when necessary, verification of external dosimetry information 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 the availability and condition of protective equipment, and documentation of accidents and incidents.

Environmental records document radiologically significant characteristics of the environment and include results of measurements of the radionuclide contents of the air, ground, and water. These records can be valuable in reconstructing the doses received by 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 records are used for quality control purposes to ensure the accuracy of radiological measurements.

REPORTING

Regulations require that Nuclear Regulatory Commission licensees advise each worker annually of his or her total radiation dose for that year and the total career dose. If a former worker requests dose information, a licensee must furnish a report of that worker's exposure within 30 days of the time of the request or within 30 days after the exposure has been determined by the licensee (CFR, 1998b).

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4

Current Paradigms for Radiation Protection in the U.S. Army

The U.S. Army has three separate programs to control the radiation exposures of 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 who use radioisotopes, and technicians who maintain radioactive commodities such as radiation detection instruments and calibration sources.

The second applies to soldiers whose primary occupation does not usually expose them to radiation. These are the soldiers who might respond to a military situation, such as that covered by Allied Command Europe Directive (ACE) 8063 (NATO, 1996), in which radiation is present, but at doses not exceeding 700 millisievert (mSv).

The Army's third radiation protection program is intended to apply only during situations of extremely high radiation exposure, such as nuclear war.

OCCUPATIONAL EXPOSURE

In peacetime, radiation exposures of soldiers who are considered to be at such risk in the execution of their duties are governed 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 standards, which for the most part reflect the recommendations of the International Commission on Radiation Protection (ICRP) and the National Council on Radiation Protection and Measurements (NCRP).

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Radioactive commodities in the U.S. Army are controlled, as they are in civilian industrial operations, under licenses issued by the Nuclear Regulatory Commission. Exposures that could result from the fabrication, maintenance, or application of these radioactive commodities are subject to control under civilian regulations (CFR, 1991) that tend to adhere to the general philosophy and implement practices espoused by 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), whereas the protection of individual soldiers is a medical function under the purview of the Office of the Surgeon General (OTSG, 1995a, b). Two medical documents from the Office of the Surgeon General constitute the bulk of the individual radiation protection program in the Army. Although the regulations provide a measure of radiation protection for soldiers that parallels that for civilians in similar environments and under similar circumstances, they do not extend that same protection in militarily unique missions, as the following excerpt from Army (Medical) Regulation 40-14 demonstrates (OTSG, 1995a):

> *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.
>
> (Emphases have been added.)

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NON-OCCUPATIONAL EXPOSURES UP TO 700 MILLISIEVERT

Between the 50-mSv occupational annual dose limit and the 700-mSv threshold for the development of acute health effects that become a concern during nuclear war, there is a broad band that has just recently been addressed by Army planners. ACE Directive 80-63 (NATO, 1996), developed by Army and North American Treaty Organization (NATO) planners, is an encouraging step in filling that void.

This committee's interim report (IOM, 1997) described and offered a detailed critique of the August 1996 version of NATO ACE Directive 80-63. The ACE Directive (NATO, 1996) is reprinted as Appendix A of this report. The guidance for radiation safety in this middle ground is evolving as the Army considers this committee's interim report recommendations and develops policies and procedures regarding the needs of the soldier for radiation safety in the field. Since the Institute of Medicine publication of the interim report, NATO and the U.S. Army have each held meetings to further develop policies related to low level radiation. The U.S. Army Nuclear and Chemical Agency (USANCA) coordinated a joint-service meeting to establish recommended U.S. positions for representatives of the United States to take to NATO meetings. Among other recommendations (USANCA, 1998), that group drafted a revised Operational Exposure Guidelines table. Table 4-1 displays the table as it appeared in the August 1996 draft of the ACE Directive (NATO, 1996). Table 4-2 is the revised version distributed by the U.S. Army in May 1998.

The revised table differs from the ACE Directive Annex A most by replacing the use of the narrative descriptors of "State"-expressed as *No, Normal, Minimal, Limited, Increased,* or *Significant Risk-with* quantitative estimates of "Increased Risk of Long Term Fatal Cancer"-expressed as *None, 1:4,000, 1:400, 1:200, 1:80, and 1:30.* The footnotes have been revised minimally.

HIGH-LEVEL EXPOSURES IN NUCLEAR WAR

During times of war the radiation to which soldiers are exposed has been assumed to be the result of nuclear weapons detonation. Soldiers have been trained to operate in a nuclear environment since the advent of nuclear weapons, and such training continues to this day (HQDA, 1983, 1992, 1993). The radiation protection practices to be used under these conditions have been driven by the need for soldiers to survive to accomplish their immediate missions. In this scenario, the risk of stochastic effects, including cancer, has been a secondary concern.

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TABLE 4-1. Draft (August 2, 1996) Operational Exposure Guidance for Low-Level Radiation

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

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[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 because of the employment of effective respiratory protection and other measures. All doses should be kept as low as reasonably achievable (ALARA). This will reduce the risk to the individual soldier and will retain maximum operational flexibility for future employment of exposed soldiers. The use of the measurement millisievert (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 millisievert is not possible, ACE forces will use centigray. For whole-body gamma irradiation, 1 cGy is equivalent to 10 mSv.

[b] Risk is of long-term health consequences, primarily induction of fatal cancer starting 2 years postexposure. Total lifetime risk is assumed to be 4 to 7 percent per 100 cGy (1,000 mSv). This is in addition to the 20 to 25 percent 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. 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.

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

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

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

SOURCE: NATO. ACE Policy for Defensive Measures against Low Level Radiological Hazards during Military Operations; ACE Directive Number 80-63. Brussels, Belgium: Supreme Allied Headquarters Europe, August 2, 1996 (with minor editorial revisions).

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TABLE 4-2. Revised, Low Level Radiation Guidance for Military Operations (Draft, Received May 1998)

Total Cumulative Dose[a]	Radiation Exposure State Category	Recommended Actions	Increased Risk of Long-Term Fatal Cancer[b]
[<0.5 mGy] 0-0.05 cGy	0	• None	None
[0.5-5 mGy] 0.05-0.5 cGy	1A	• Record individual dose readings • Initiate periodic monitoring	1:4,000
[5-50 mGy] 0.5-5 cGy	1B	• Record individual dose readings • Continue monitoring • Initiate rad survey • Prioritize tasks • Establish dose control measure as part of operations	1:400
[50-100 mGy] 5-10 cGy	1C	• Record individual dose readings • Continue monitoring • Update survey • Continue dose control measures • Execute priority tasks only[c]	1:200
[100-250 mGy] 10-25 cGy	1D	• Record individual dose readings • Continue monitoring • Update survey • Continue dose control measures • Execute critical tasks only[d]	1:80
[250-700 mGy] 25-70 cGy	1E	• Record individual dose readings • Continue monitoring • Update survey • Continue dose control measures • Execute critical tasks only[e]	01:30

[a] The use of the measurement millisievert 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 millisievert is not possible, U.S. forces will use centigray. For whole-body gamma irradiation, 1 cGy is equal to 10 mSv. All doses should be kept as low as reasonably achievable (ALARA). This will reduce the risk to individual soldiers and will retain maximum operational flexibility for future employment of exposed soldiers.

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[b] This is in addition to the 1:5 and 1:4 incidence of fatal cancer among the general population. Increased risk is given for induction of fatal cancer (losing an average of 24 years of life for personnel ages 20 to 30 years). Total lifetime risk is assumed to be 4 to 7 percent per 100 cGy (-1,000 mSv). It must be noted that higher radiation dose rates produce proportionally more health risks than the same total dose given over a longer period.
[c] Examples of priority tasks are those missions to avert danger to persons or to prevent damage from spreading.
[d] Examples of critical tasks are those missions required to save lives.
SOURCE: USANCA. Current U.S. Positions on Low Level Radiation (LLR) in Military Operations. Memorandum for Committee on Battlefield Radiation Exposure Criteria, Institute of Medicine, May 18, 1998 (with minor editorial revisions).

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. The U.S. Army implements these criteria through the use of Field Manual 3-3-1 (HQDA, 1994) to control the cumulative radiation dose received by combat units. One of four radiation exposure state (RES) categories (Table 4-3) 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 that the readings be passed up the chain of command. Records of summary exposure data are maintained at the battalion level for subordinate company- and platoon-sized units and are then forwarded to higher commands, which keep more broadly aggregated records.

Currently, the U.S. Army does not record the doses received by individual soldiers who are exposed to radiation on the battlefield. Doctrine requires that two soldiers per squad (about 25 percent; a platoon usually has three squads) have self-reading dosimeters. Until it implements the use of individual dosimeters, the Army assumes that each soldier receives an individual dose equal to that of the average for the platoon (HQDA, 1994). The Army eventually plans to equip each soldier with a dosimeter, but the type expected to be deployed (DT236) will be useful for recording only external doses 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 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. Although this creates severe management problems, it is intended to keep personnel from incapacitation due to overexposure to radiation.

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TABLE 4-3. Nuclear Radiation Exposure Status and Degree of Risk Exposure

Radiation Exposure Status Category[a]	Total Past Cumulative Dose[b]	Possible Exposure Criteria for a Single Operation That Will Not Result in Exceeding the Dose Criteria for the Stated Degree of Risk[c]
RES-0	No exposure	Negligible risk: ≤50 cGy (500 mGy) Moderate risk: ≤70 cGy (700 mGy) Emergency risk: ≤ 150 cGy (1,500 mGy)
RES-1	More than 0, but less than or equal to 70 cGy (700 mGy)	Negligible risk: <10 cGy (100 mGy) Moderate risk: ≤30 cGy (300 mGy) Emergency risk: ≤110 cGy (1.100 mGy)
RES-2	More than 70 cGy (700 mGy), but less than or equal to 150 cGy (1,500 mGy)	Any further exposure is considered to exceed a negligible or moderate risk. Emergency risk: ≤40 cGy (400 mGy)
RES-3	More than 150 cGy (1,500 mGy)	Any further exposure will exceed the emergency risk.

[a] Radiation status categories are based on previous exposure to radiation. 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 the actual state of health of exposed personnel.
[b] All exposures to radiation are considered total body and simply additive. No allowance is made for body recovery from radiation injury.
[c] 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. 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 U.S. Army radiation safety program is a three-tiered system that addresses the following:

1. exposure to soldiers doing routine radiation jobs, absent hostilities;
2. exposure that is incident to military operations but that is at levels below those that can cause acute effects; and

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3. exposure that is incident to nuclear war and that is at levels that can cause acute effects.

The first level is comparable to civilian radiation safety programs and treats soldiers in a manner similar to that in which occupational workers who are engaged in radiation practices are treated. At the second level, soldiers are engaged in military activities that may or may not be comparable to routine practices and that can resemble emergency response activities. Unlike in the first level, in the second level the military mission may override or curtail radiation safety considerations. The highest level is uniquely military and involves combat in times of nuclear war. At these radiation exposures, lethality or acute effects are expected. This level is beyond the scope of this report and will not be discussed further.

In the next chapter, the committee discusses how the current military programs, when augmented by the proposed guidance, meet the scientific, ethical, and legal requirements discussed previously.

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Army Radiation Protection and Safety Programs in Light of Civilian Standard Practices and Recommendations for Improvement

The previous chapters have described the potential adverse health consequences of radiation exposure, have outlined currently accepted methods for limiting those consequences, and have described current U.S. Army approaches to limiting those consequences. Using that information as background, the committee discusses here how well the Army radiation protection and safety programs are structured to protect soldiers. This report's focus, reflecting the charge to the committee, is radiation doses of 700 millisievert (mSv) or lower that are incurred during military operations.

The Army has published guidance for the control of doses received from routine occupational exposures and those associated with nuclear war. Its work to incorporate concepts of the Allied Command Europe (ACE) Directive (NATO, 1996) is an encouraging step in the development of control measures for other situations. The committee realizes that the Directive was initiated for a specific mission (Bosnia) and that the U.S. Army recognizes its limitations. The comments that follow should be viewed as constructive; in no way does the committee intend them to diminish the significance of the progress that the Army has made toward the control of the complete spectrum of radiation hazards both on the battlefield and in operational situations other than war. In its interim report, the committee recommended that the ACE Directive be revised to ensure completeness and clarity. The U.S. Army has been working in that direction.

The first part of this chapter reprints the interim report's discussion (IOM, 1997) evaluating the ACE Directive in light of standards in the civilian sector. The committee continues this chapter with information and guidance on what it

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considers to be three essential components of a radiation protection program: training, recordkeeping, and reporting.

REVIEW OF THIS COMMITTEE'S INTERIM REPORT[1]

Underlying Philosophy of Radiation Protection

The discussion begins with an assessment of the underlying philosophy of U.S. Army radiation programs. The ACE Directive (NATO, 1996, § 1-2.), which forms the developing basis for U.S. Army policy regarding operations other than war, states 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: 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's policy statement. This committee brought this to the attention of the Army in its interim report (IOM, 1997) in its recommendation that the Army provide soldiers the same level of radiation protection that civilians working in similar environments receive.

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 milligray (mGy)/hour (0.0003 rad/hour), and commanders are to establish dose control measures as part of operations at a cumulative dose of 5 to 50 mGy (0.5 to 5 rad) (NATO, 1996). These may be thought of as reference levels—values at which certain actions should occur.[2] 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 the International Commission on Radiological Protection (ICRP).

The analogy of military action as intervention is not perfect. ICRP sees an intervention as an action directed at the radiation source, for example, to prevent

[1] This section is excerpted from the committee's interim report (IOM, 1997), with minor editorial corrections.

[2] The only place that the committee encountered defined exposure limits in the ACE Directive is in setting maximum exposure guidance prior to a mission (ACE Directive [NATO, 1996] para. 1-3f(2)). This is much like ICRP's recommendation that doses greater than about 500 mSv not be permitted except to save a life (ICRP, 1991a).

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further contamination or to put out a fire in a reactor. In the case of the U.S. 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. The provision of routine guard services would no longer be part of the intervention. At that point, exposure levels should be well known and the dose that the soldier receives should therefore be kept not only within accepted dose limits but also as low as reasonably achievable. This activity should be controlled as a practice, not as an intervention.

The committee firmly acknowledges that a military operation is a unique situation in which simple definitions of practices and interventions become complex and conditions may change quickly. In the civilian version of the scenario outlined above, 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. For nonemergency situations, the ACE Directive does not provide guidance that would afford protection to soldiers at a level appropriate for a practice.

Interim Report Recommendations

The U.S. Army should:

1. Provide soldiers the same level of radiation protection provided to civilians working in similar environments. The ACE Directive appears to manage all military missions involving radiation exposures as interventions. Although 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.

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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 described previously. 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 ICRP 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 that 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 practices and interventions separately. It would seem reasonable for the commander to have the authority to determine which of these frameworks to follow on the basis of the military mission.

Terminology

The committee considers some terms in the ACE Directive (NATO, 1996) misleading. The first and by far the most serious one 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. Although the terminology may be perfectly clear to those involved in developing the guidance, it probably will be misunderstood by others. The U.S. Army's use of this term to describe doses that approach thresholds for acute effects could easily be misinterpreted as an intent to mislead soldiers on the seriousness of such exposures.

The committee has concerns about the terms used to describe the effects of dose categories in the table in Annex A of the ACE Directive (NATO, 1996).[3] *No risk* is used to describe the effect of doses of less than 0.5 mGy (0.05 rad). This is inconsistent with international positions on the effects of radiation, specifically, the assumption that even low radiation doses may produce some deleterious effects. Likewise, the term *normal risk* incorrectly implies that an exposure

[3] The committee notes that the United States has drafted a revised table for the draft of Annex A to the ACE Directive that replaces the narrative terms for risk *(none, normal risk, minimal risk, limited risk, increased risk,* and *significant risk)* with quantitative risk estimates *(none, 1:4,000. 1:400, 1:200, 1:80, 1:30).*

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of 0.5 to 5 mGy (0.05 to 0.5 rad) adds no additional risk to that from exposure to natural background radiation, 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.[4] *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 automatically appended to radiation. Rather, it should be used advisedly to identify the potential for significant health consequences.

Interim Report Recommendations

The U.S. Army should:

4. Not use the term *low level* to describe the radiation dose range of 50 to 700 mGy (5 to 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 radiation exposure state (RES) categories labeled RES 0 and RES IA in the table of exposure guidance in Annex A of the ACE Directive. The description of 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 Assessment

One of the important aspects of the evolving guidance for intermediate doses of radiation is the prospective risk assessment in which the commander tries to determine the significance of the radiation situation on the field of military operations, whether it is a battlefield or an area of peacekeeping activity. The U.S. Army guidance documents reviewed by the committee (ACE Directive, etc.) have discussed this topic, but only in the context of the physical radiation present in the area of operations. In Chapter 2 of this report, the committee reviewed the accepted scientific methodology for risk assessment.

[4] See, for example, ACE Directive § -2.a (NATO, 1996).

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The ACE Directive (NATO, 1996, §1-3.a. and c.(l)) indicates that there is a prospective assessment of risk, high or low. It is unclear whether this refers to (1) intelligence assessments of the likelihood of radiation contamination or (2) the magnitude of measurable levels of radiation contamination.

In principle, the committee agrees with the Directive's requirement for the use of "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 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 practical and durable instruments that can directly measure beta- and alpha-radiation dose rates in the field.

Interim Report Recommendations

The U.S. Army should:

7. Develop requirements for measuring, interpreting, and responding to airborne and surface contamination (particularly that containing alpha and beta emitters). Guidance should define the levels of alpha and beta contamination that would trigger the 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 of the ACE Directive (NATO, 1996, §1-3.a.) whether risk (high or low) refers to (1) intelligence assessments of the likelihood of radiation contamination or (2) 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 an area with low level contamination 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.

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Definition of a Radiological Area

The ACE Directive (NATO, 1996) defines a radiological hazard area as anywhere that the dose rate is in excess of 0.002 mGy/hour (0.0002 rad/hour). This dose rate is approximately 20 times the background radiation dose rate found in the United States (NCRP, 1987a) and 1/10 the maximum dose rate allowed for uncontrolled areas that members of the public might frequent. If a soldier were to spend a year in an area with such a dose rate—.002 mGy/hour (0.0002 rad/hour), 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 (ICRP, 1991a). Continuous exposure at this level would not exceed the current annual exposure limit of 50 mSv for U.S. radiation workers 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

Current thinking in the U.S. Army requires that, in deciding to allow a soldier to be put at risk of exposure to radiation, a commander 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.

The 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 soldiers and is fragile and prone to error during 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 (NATO, 1996). Dosimeters that can detect thermoluminescence can be used to monitor dose at low dose levels. These 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 ACE Directive, it may be difficult to do with currently available hardware.[5]

[5] As a direct result of the committee's discussion of inadequacies in current dosimetry capability in its interim report (IOM, 1997), the Defense Special Weapons Agency has funded the development of a fly-away external dosimetry laboratory. The U.S. Air Force Center for Radiation Dosimetry is planning an operational test involving a nuclear weapons accident scenario in 1999 (DSWA, 1998).

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The level of exposure at which dosimetry is recommended is stated in the Operational Exposure Guidance table of the ACE Directive. At 0.5 mGy (0.05 rad), the beginning of RES category labeled "IA," the commander is advised to "record individual dose readings [and] initiate periodic monitoring" (NATO, 1996, p. A-1). It is not clear what circumstances would lead to the start of dosimetry for individuals. If dosimetry for individuals has not yet begun, how is it determined that the 0.5-mGy (0.05-rad) level has been exceeded, triggering the start of periodic monitoring? One assumes 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 mGy or more. Similarly, in civilian practice, the decision to issue individual dosimeters for monitoring can be made on the basis of projected doses. However, the ACE Directive requirement is considerably more stringent than that commonly followed in occupational programs and the rest of the U.S. Department of Defense (DoD) (DoDI, 1996).

DoD requires the monitoring of individual doses only when doses are above 5 mSv (0.5 rem), which is 10 times the level recommended by the ACE Directive (NATO, 1996).

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 zone with low level contamination without dosimetry. It is possible that this could result in exposure from unknown, localized hot spots that could cause the individual to receive doses above the monitoring threshold in Annex A.

Dose Units

Although 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, the practice is not internationally accepted. The same may be said for the unit of effective dose, the centisievert, as a pseudonym for the rem.

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

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Internal Dose

Although the ACE Directive (NATO, 1996) requires determination of external whole-body doses for individuals, 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 I of the table in Annex A to the ACE Directive (NATO, 1996, p. A-1) 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 they are in a "radiological hazard area" (NATO, 1996, p. 1-6)—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 the background level 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 concentration of radioactivity in the air 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, thereby jeopardizing the mission, while perhaps also increasing the risk of other nonradiation hazards.

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 (NATO, 1996) 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

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appear that individual dose records indicating prior occupational and other exposures will be available to commanders when they are assigning RES categories.

Interim Report Recommendations

The U.S. Army should:

11. Review its dosimetry capabilities and determine if they are adequate to support the use of the Operational Exposure Guidance in the ACE Directive. 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 the specificity of the dosimetry program guidelines in subsequent versions of the ACE 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 U.S. 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 inhalation or ingestion of radionuclides. This may occur if they are unaware of the 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 to be a problem, as noted previously for the Atomic Veterans. More recently, potential chemical exposures during the Persian Gulf War at Kamisiyah, Iraq (DoD, 1996; Schafer, 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 should 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 as the standard unit of effective dose and the milligray as the unit of absorbed dose. There are three reasons for this recommendation. First, the units currently used in the ACE Directive—centigray and centisievert—are not internationally accepted scientific units. Second, by using millisievert, all doses to individuals can be compared to I year's nominal U.S. background dose from external sources (1 mSv). This should make it easier for

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soldiers to understand their exposures.[6] 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 I and that 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 state (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 that 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. Although 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).

Reference Levels for Operational Exposure Guidance

The ACE Directive Operational Exposure Guidance table (Annex A [NATO, 1996]) subdivides the some-exposure category (RES-1; Table 4-1 in this report) of existing Operational Exposure Guidance (HQDA, 1994; NATO, 1986). Each level is accompanied by a narrative description of the risk corresponding to a dose range 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 the planning of 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,[7] individual dosimetry, it would be unreasonable to expect to control doses for all individuals in

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

[7] Some dosimeters like the IM-92 dosimeter can be read by the soldiers themselves. at any time, enabling them to control their dose during the mission. Other dosimeters (e.g., the DT-236 dosimeter) can only be read by special equipment not available to individual soldiers during a mission.

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the first two RES categories (0 to 0.5 mGy [0 to 0.05 rad] and 0.5 to 5 mGy [0.05 to 0.5 rad]).

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

At doses ranging from 0.5 to 5 cGy (5 to 50 mGy or 0.5 to 5 rad; RES Category 1B), the Operational Exposure Guidance recommends "establishing dose control measures as part of operations" (NATO, 1996, p. A-1). If one considers that the dose limit for the public used by the U.S. Nuclear Regulatory Commission until 1994 was 5 mSv, this level for beginning dose control might be appropriate. However, the current limit for public exposure is I mSv (CFR, 1991; ICRP, 1991a). In addition, the ACE Directive (NATO, 1996) itself institutes controls of radiation exposure beginning at 0.002 mGy/hour (0.0002 rad/hour). From this it would appear that some measures of control may be appropriate below the RES Category 1B level.

RES Category IC indicates that only priority tasks are to be attempted between 5 and 10 cGy (50 and 100 mGy or 5 and 10 rad). Priority tasks are defined as those required to avert danger to persons or to prevent damage from spreading. This level is comparable to Environmental Protection Agency (EPA, 1991) guidance that allows up to 100 mSv (10 rem) for similar tasks.[8] It is also within the 500 mSv limit recommended by the National Council on Radiation Protection and Measurements (NCRP, 1993). In the next higher exposure categories—RES Category 1D (10 to 25 cGy [100 to 250 mGy or 10-25 rad]) and RES Category IE (25 to 70 cGy [250 to 700 mGy or 25 to 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 category is described as increased risk and the higher category is described 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 RES Categories 1D and 1E are in keeping with that guidance.

Interim Report Recommendations

The U.S. Army should:

19. Include radiation doses from internal sources (e.g., from inhaled airborne radioactivity) in applying reference levels in Operational Exposure Guid

[8] For comparisons in this paragraph the committee is assuming that the exposure is to gamma or x-ray radiation and that 1 mGy is approximately equivalent to 1 mSv (rad □ 1 rem).

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ance. The reference levels shown in the ACE Directive Operational Exposure Guidance table (Annex A [NATO, 1996]) 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 that 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 ACE Directive are generally appropriate, the actions recommended at each level lack specificity. Future versions of the ACE 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 U.S. 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 (NATO, 1996) should be expanded to include dose limits and reference levels appropriate for a practice as well as an intervention.

Recordkeeping

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

The ACE Directive (NATO, 1996, §1-3.f.(3)) requires commanders to ensure that the dose that 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 (NATO, 1996, § 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 U.S. Nuclear Regulatory Commission guidelines or U.S. Army regulations. The committee assumes

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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, or environmental data). Ultimately, it may be necessary to link this information from its repository to an individual for purposes of compensation determinations or epidemiologic study.

GUIDANCE ON RADIATION PROTECTION

Although the first part of this chapter has focused specifically on the August 1996 draft of the ACE Directive (NATO, 1996), in this second section the committee broadens its discussion. The topic remains exposures of less than 700 mSv; and the task remains the presentation of the committee's evaluative findings on the basis of its integration of (1) information about civilian standard practices, (2) its understanding of current U.S. military practices, and (3) the process of committee deliberation that defines the Institute of Medicine-National Academy of Sciences approach.

Throughout the report, the committee discusses the topics of training, recordkeeping, and reporting in sequence. In a good radiation protection program all three must be intricately interwoven. Training should impart some basic understanding of radiation, communicate the risk, help the soldier to understand the ramifications of risk perception, and then place that knowledge in a context whereby the risks associated with radiation exposure can be compared with other non-radiation-related risks. The soldier then can draw upon this foundation to (1) protect himself or herself and others during an exposure situation, (2) know which pieces of information are important to obtain and record, (3) act to notify whomever should know about exposure or effects, and (4) use his or her own dose report to help guide his or her own future occupational, avocational, and health care activities. In addition, through training, the military attempts to teach commanders how to decide when it is appropriate to put subordinates at risk (justification) and how to do so to minimize short- and long-term harm while also achieving the military mission (optimization).

Therefore, training content includes conveying the value of information (e.g., records are important and notification of personnel is important) and the lesson that recordkeeping and reporting procedures are valuable only if the soldier knows (through training) what to measure and how to do so, what to record, and what to do with that information once it is recorded.

The common thread is communication. Accurate and appropriate information must be maintained so that it is available to be given to the right people at the right time. Furthermore, this communication must be carried out within an ethical framework in which the government seeks to meet its military objectives,

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protect the health of military personnel, and take responsibility for the health consequences resulting from its decisions.

Information is vital to sustaining protection. When existing technology allows detection of radiation exposures, advance notice of radiation exposures is the goal. When feasible, radiation levels should be monitored in settings of suspected exposure. The levels of radiation that may involve short- or long-term risks need to be predetermined. Chains of command should be prepared to disseminate radiation warnings quickly and efficiently. If possible, soldiers should be equipped with devices to detect the levels of radiation in the operational field in cases in which significant radiation exposure is expected. They should not only know how to operate the devices, but should also understand how to interpret the readings that these devices provide.

In the military, choice is inherently constrained, and the nature of volunteering likely varies widely from situation to situation. The nature of military service has been used by U.S. courts as the primary rationale for denying service personnel the right to sue the U.S. military for injuries sustained while on active duty. In the leading case, *Feres v. United States* (1950), the U.S. Supreme Court ruled that military personnel may not sue the federal government for injuries sustained on active duty because (1) the Federal Torts Claims Act (FTCA; passed in 1948) does not provide for such lawsuits, (2) it would be unreasonable for the military to have to follow the liability laws of the various jurisdictions in which soldiers are posted, and local law would determine liability under FTCA, (3) the relationship between the soldier and the armed forces was "distinctively federal in nature," and (4) the Veterans Benefits Act provides a no-fault-based scheme to compensate veterans for service-connected and non-service-connected disabilities (Dalton, 1996).

In addition to these technical points of FTCA, the U.S. Supreme Court noted 4 years later in *United States v. Brown* (1954) that the *Feres* doctrine was based on the peculiar and special relationship of the soldier to his superiors, the effects of the maintenance of such suits on discipline, and the extreme results that might obtain if suits under FTCA were allowed for "negligent orders given or negligent acts committed in the course of military duty." Since *Brown* involved a claim by an honorably discharged soldier who was injured during knee surgery at a Veterans Administration (VA) hospital 6 years after discharge, the Court held that the *Feres* doctrine did not apply to him and that he could sue the VA for negligence.

Because contracting with a private military supplier creates a relationship that is as "distinctly federal in character" as the relationship between the government and its soldiers, soldiers may not sue private suppliers for defective products *(Stencel Aero Engineering Corp. v. United States,* 1977). Also, because of the need for strict military discipline, soldiers are barred from suing superior officers, even for violation of their constitutional rights *(Chappell v. Wallace,* 1983; Dalton, 1996).

For volunteering to be real, the soldier must be informed of the nature of the task and its risks and have the real option to decline to participate. Because the

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U.S. military is also the employer of the soldier, the military has an independent obligation to the volunteer to minimize the risks as much as is reasonably possible. This can be done in a number of ways, including the use of planning, the use of protective equipment, and the exploration of less risky alternatives. Unlike the civilian, the military volunteer incurs no additional obligations by beginning a task: it is the nature of his or her initial agreement to perform the task and the nature of military service itself that would obligate the individual to complete the task to the best of his or her ability. Because the military knows that especially hazardous assignments will predictably occur and that volunteers will be sought for such assignments, the military has an added ethical obligation to plan for such occasions and minimize the risk of harm to the individual volunteers.

Training

The committee emphasizes four overlapping purposes of training:

1. to address and fulfill ethical responsibility,
2. to address and fulfill legal responsibility,
3. to provide knowledge, and
4. to provide understanding.

In terms of ethics and humanitarianism, as well as military preparedness and effectiveness, death and disease should be prevented. Although this may not be possible in an acute scenario, the training of soldiers in radiation exposure protection and safety would meet this mandate. The employer (in this case, the military) has an obligation to provide the employee (in this case, the military member) with a basic understanding of the risk as well as the means of prevention and protection. Knowledge of protective measures and the correct use of monitoring equipment can help to overcome fear of the unknown and therefore makes for a more effective soldier. Finally, the soldier should understand the effects of radiation exposure and related acute and long-term effects.

In general, the committee recommends that the U.S. Army—whenever possible, given military organization and operational exigencies—be guided by the philosophy and content of civilian radiation protection and safety programs (as described in Chapter 3). This training would include, at a minimum, an understanding of the threat of radiation exposure; the principles of protection; the importance of communication, including recordkeeping; the need for follow-up after an exposure in tandem with information on possible acute effects, long-term effects, and future exposure; means of identifying actual or potential sources of radiation emission; decontamination procedures; and, in the event of exposure, the treatment of symptoms of acute radiation effects and the prevention of delayed effects. To achieve this training of soldiers, the Army must adequately

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train the commanders in both the radiation-related information and the risk communication techniques that they would need to inform their troops.

Recordkeeping and Reporting Requirements

In addition to the requirement that DoD maintain radiation exposure data for all its personnel, the committee strongly recommends that each military member so exposed be provided annually and on termination of his or her service with a written document specifying the magnitude of each exposure (if possible) and the location(s) of such exposure(s) during his or her service. A copy of this information can then be made available to the U.S. Department of Veterans Affairs for future determination of the service connection of the disability and follow-up medical care if required. If possible, the exposure data notification document should include both a list of the agents to which the person was exposed and a general statement of the potential health consequences related to those exposures. The quality of the information provided will vary depending on whether the military operation was during war or peacetime, with more detail expected during peacetime activities.

Adequate recordkeeping of radiation exposures has two important ethical facets. First, recordkeeping requirements should respect, to the extent possible, the privacy of the individual and the confidentiality of that person's data. Individuals are entitled to know the purposes of data collection on radiation exposures, how this information will be used, those who may have access to the data, and the circumstances under which they are stored. Individuals should have access to their medical and exposure records and should be allowed to make corrections if warranted. The reliability of such data should be guaranteed by the military, with updating as necessary. Records should be kept secure from unauthorized users. Authorized access to records with personal identifiers, including individual medical records, should be limited to those who need access in the interests of the patient, certain types of epidemiologic research, or other justifiable uses. Even in such circumstances, the military should follow ethical standards of research by hewing to the federal rules laid out in the "Common Rule" (CFR, 1993) or by developing its own set of policies and procedures for consent and other research ethics.

Second, recordkeeping requirements should further the interests of military personnel and the military. There are three primary reasons in support of systematic recordkeeping:

1. *Individual exposures:* Military personnel exposed to radiation are entitled to receive adequate medical treatment at present and in the future for related injuries. To this extent, any information that may be beneficial to preserving the health of military personnel should be systematically kept in a personally identifiable medical file for each person. The military's determination of what infor

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mation may be important for documentation (for example, personal radiation monitoring data) should be based on sound medical and scientific findings.

2. *Cumulative recordkeeping:* Comprehensive recordkeeping of incidences of radiation exposure over time provides the military with the means to track and reduce or prevent harmful exposures and subsequent health effects in the present and in the future.
3. *Population exposure:* Information collected through comprehensive recordkeeping for those exposed to radiation could be highly beneficial in assessing potential harm to populations in the event that they are exposed.

Although records of radiation exposures may be kept for a variety of legitimate purposes, information should be collected pursuant to these objectives and not merely for the sake of having the information. No secret databases or uses of information should exist unless they are consistent with sensitive and ethical military objectives that require justified temporary nondisclosure. Declassification of secretly held information must be made as soon as possible. Procedures to determine legitimate uses of information should be standardized prospectively. Users who do not require information with personal identifiers should not have access to such information. Disclosures of such information, when authorized, should follow the least-intrusive disclosure principle. Disclosures must be the narrowest in content, must be the least identifiable and sensitive, and must go to the fewest number of persons as reasonably necessary to achieve a stated and justified objective. Information that has personal identifiers and that has been gathered for one purpose should not be disclosed for another, inconsistent, or secondary use without the consent of the individual. Although the dual goals of maintaining privacy and achieving comprehensive and accurate recordkeeping may seem incongruous, in fact, they can both be accommodated in a properly designed and implemented health information system.

Recordkeeping in Military Settings

The privacy of health-related information in military settings is in many ways distinct from that in the civilian sector. Military service explicitly and implicitly requires individuals to waive some of the privacy of their health information. Thus, for example, all military personnel can be required to undergo testing for drugs and sexually transmitted diseases as part of their agreement to serve in the military even though civilians cannot constitutionally be required to submit to such tests without some substantial justification. These test results become part of a military member's medical file, which may be circulated among perhaps thousands of people during the course of a career and afterward. Many military veterans use federal health care services through the U.S. Department of Veterans Affairs, to which copies of their military medical records may be forwarded.

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Despite these and other exceptional waivers of privacy as part of military service, military personnel are entitled to some expectation of basic levels of accuracy, privacy, confidentiality, and security in the keeping of records of their exposures to radiation. To clarify these expectations, accuracy, privacy, confidentiality, and security in these contexts require definition. The *accuracy* of records means that the data that are collected should be complete, material, current, and correct. Health information *privacy* may be defined as an individual's claim to control the circumstances in which personally identifiable (versus anonymous or linkable) information is collected, used, stored, or transmitted. *Confidentiality* refers to privacy interests arising out of a specific relationship with the person about which information is gathered. In this context, a soldier may expect that a military physician whom he or she has seen for a medical condition will keep that information confidential, despite the dual fiduciary relationship of the physician to the patient and the physician's commanding officer. *Security* denotes the technological, organizational, or administrative processes designed to protect data systems from unauthorized access or unwarranted disclosures, modification, or destruction (Gostin, 1995, 1997; Gostin et al., 1996).

Consistent with these definitions, even the most secure system of military medical record management cannot maintain the privacy of records because no collection of information is free from unauthorized access. Although privacy expectations arise, in part, from the ethical principle of autonomy, they are not in any sense absolute. Medical records, by their nature, are created to be shared with others. Health information is lawfully exchanged among numerous parties, regardless of an individual's claim to control the circumstances in which it is transmitted.[9] In the military individual interests in health information privacy must be balanced against the individual's own interests in comprehensive and accurate recordkeeping, as well as the competing interests of the military and clinicians in information concerning radiation exposure. The result in military settings is a privacy trade-off between the privacy of the medical records of military personnel and the communal defense-oriented interests of the military.

[9] For example, state reporting requirements mandate the reporting of instances of multiple diseases to state authorities, regardless of whether an individual diagnosed with the condition consents.

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6

Decisionmaking by Commanders

Earlier chapters have emphasized the commander's duty to protect subordinate soldiers, including justification and optimization of radiation exposures. The purpose of this chapter is to provide a practical methodology by which commanders, while trying to achieve a military objective, can make decisions in the field when radiological risks are or may be present. This duty requires that the commander consider the entire context of the situation and then balance the anticipated benefit and risk. This is often difficult or impossible to achieve because of the limited quantifiable information available. Although the commander should also have a general idea of the benefit of the operation and the ongoing balancing of national security interest with risks to individuals, it is the quantification of the short-and long-term costs of the operation that this chapter addresses.

The commander is the immediate, at-the-scene, decisionmaker. The decisions a commander makes, however, are based on an amalgam of information, training, and perspective that the government (through the Executive Branch via the military, the Congress, and the courts) continually develops. The sole responsibility does not rest with the commander. Rather, the commander is the last link in that process for a given operational decision. The Department of Defense must prepare the commander for that task, in terms of training and support. That support, which has traditionally involved military intelligence information, casualty estimates, and the necessary equipment and supplies for a given mission, now should also include short- and long-term health risk estimates.

INFORMATION

The risk or cost evaluation often begins with information from intelligence-gathering activities. The detail and validity of such intelligence can vary signifi

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cantly across situations. In hostile situations, the amount of information available may be very limited, but decisions must nonetheless be made. In peacekeeping or other nonhostile operations, however, the commander may have the option of delaying a decision while gathering more detailed information on the scope and magnitude of potential risks.

JUSTIFICATION

Commanders now use data derived by mathematical models to estimate the number and type of acute injuries, including the anticipated numbers of deaths, that would likely result from a given operational situation. These estimates are used to assess combat capabilities and the need for supplies, such as bandages and beds, and replacement personnel. This committee recommends that commanders consider the long-term consequences of radiation exposure when assessing the costs associated with a situation. Although individual commanders often strive to do so, the military has not developed formal guidance to support the assessment of the long-term health risks and consequences of operational decisions. This results, in part, because law and regulations leave the management of long-term injuries and conditions to the U.S. Department of Veterans Affairs. In addition, because of the need to keep soldiers operational on a battlefield, in their assessments commanders may be willing to accept an inappropriately high likelihood of long-term health effects to prevent personnel performance from diminishing while the operation is underway. The committee notes that consideration of radiation-related costs alone would distort the decisionmaking process because long-term costs stemming from other, non-radiation-related, mission-related exposures (e.g., spinal cord injury or posttraumatic stress disorder) would not be assessed.

Because debilitating acute radiation injury is not caused by radiation exposure at organ or whole-body doses of less than 1,000 millisievert (mSv), the concern of major importance after exposure to those doses is long-term effects (particularly cancer). The estimation of cancer risk is complicated by a number of factors including the latent period (time between exposure and diagnosis) and the relatively high (approximately 35 percent) cancer incidence in the general population. Furthermore, rational justification in circumstances involving radiation requires not only that commanders consider the long-term effects of radiation but also that they consider and weigh the long-term health effects of other exposures and injuries. The formal inclusion of this evaluation of long-term consequences in commanders' operational decisionmaking is a relatively new concept for the military.

Despite the difficulties discussed throughout this report, the long-term health risks and effects of radiation exposure are relatively easy to quantify compared with the medical, monetary, and social costs of even clearly defined injuries such as amputation. The commander is not likely to have hard data to use in

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assessing most long-term risks, and the long-term effects of some agents may not even be known. Nonetheless, the committee finds that it is the commander's responsibility to consider long-term health consequences, in addition to acute injuries, in operational decisionmaking. In fact, hard data are often not available concerning even traditional information elements that the commander is expected to use in decisions. That task of making difficult decisions is the precise job of the commander. The commander accepts that responsibility with the expectation that DoD will give him or her the tools to carry it out.

OPTIMIZATION

After the military mission has been justified (i.e., greater benefit than cost is anticipated), the commander should optimize the plan to minimize the potential effects of any risk that is involved. The task is to complete the mission in a way that maximizes the benefit/risk ratio. Commanders may share the public perception of radiation risk, which is based largely on inaccurate or incomplete information, and may therefore attempt to avoid radiation at all costs. This is inappropriate. One goal of a radiation protection and safety training program for all personnel is to provide individuals with information and the opportunity to explore misperceptions that could contribute to such an inappropriate decision.

In addition to the implementation of radiation protection and safety training programs, military missions can be optimized in other ways. Examples of such optimization activities include providing additional protection or shielding; having more people involved in the process so that the mission can be accomplished more rapidly, thereby reducing the duration of each individual's exposure and lowering the dose received by each individual; and providing task-specific training related to the planned mission.

COMMUNICATION

Commanders and other personnel make a multitude of decisions during the planning and execution of military operations. Often, despite careful planning, situations change, particularly during execution phases, requiring that additional decisions be made. In the same manner that commanders are kept advised of critical information regarding other aspects of the situation (e.g., weather forecasts or troop movements), so should they be kept informed of radiation matters. The committee does not intend for these guidelines either to overburden the commander and his or her staff or to dictate specific actions. Rather, its purpose is to highlight the facts that (1) ensuring the welfare of soldiers includes consideration of the possible long-term health effects of radiation and (2) communicating specific information to affected individuals (as well as to others who need it to achieve success in their particular part of the mission) is important.

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From the top down, initial guidance regarding operations in environments where any potential exposure to radiation exists should include information about possible long-term health effects. This information and knowledge of adequate protective measures, including the role of personal responsibility in preventing or minimizing exposure, should provide an incentive to follow established procedures and report on deviations from normal expectations. Communications regarding radiation should be maintained as openly as communications in other leader-to-subordinate and soldier-to-soldier relationships. Commanders should tell soldiers everything they need to know both to get the job done and to protect themselves against the short- and long-term effects of radiation. Radiation risks are therefore a part of all risks inherent in military service. Although soldiers do not need training at the intensity or frequency required for workers operating in an active radiation environment, training should be used to make soldiers aware of the fundamental aspects of radiation risk and protection.

Communications about radiation should be distributed through the routine channels used by commanders and staff to transmit other data, guidance, and instructions up, down, and laterally throughout the command. When a risk of radiation exposure is present, the commander must provide specific information, such as exposure guidance, limitations, and restrictions, to all who can use it both to ensure the success of the mission and to ensure that appropriate follow-up actions are taken after completion of the operation. Some of the information is well suited for dissemination by standard procedures, such as through operations orders. Some might even become a part of the routine situation or spot reports that go up and down the chain of command.

In addition to internal communications within military organizations, civil and public affairs staff can significantly contribute to the successful completion of missions by disseminating information to the public. Depending on the magnitude of the radiation threat, the source of the radiation threat information, and awareness by others, commanders and staffs may need to provide guidance to military personnel and local civilian authorities regarding information flow among the military, the local populace, and community leaders. Although maintaining security and preventing panic or unreasonable demands on military units should be of concern, military personnel should provide adequate cautionary information to the public when appropriate. Members of the military and civilian nuclear communities recognize the importance of both of these aspects of operations and incorporate them in contingency plans for accidents and incidents. Military commanders, similarly, must include consideration of security and public reaction in the planning and execution of all operations involving expected radiation exposure.

Communications during follow-up actions are just as important as those before and during the operation. Closed-loop communications should be the norm when dealing with soldiers or any others regarding their health. If, despite all known precautions, soldiers have been placed in harm's way by performing

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duties directed by the government, the government should accept responsibility for follow-up communications and medical care. Senior leaders, military and civilian, should insist on open, candid, and honest communications with those affected. If a soldier has received a radiation dose higher than preestablished levels, the government should notify the soldier of this and provide the soldier with information about the extent of possible short- and long-term adverse health effects consistent with the exposure experienced. This should be done in a manner similar to that in which soldiers are evaluated and advised of other potentially toxic exposures. Appropriate agencies, such as the U.S. Departments of Defense and Veterans Affairs, should establish procedures for providing any follow-up monitoring or medical support that may be required. Those agencies should be proactive in notifying affected individuals of follow-up procedures. An entity that oversees the monitoring, notification, and treatment responsibilities across all agencies may be necessary to authorize the use of resources across agency lines.

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7

Follow-Up of Persons with Known or Suspected Exposure to Ionizing Radiation

Any employer has the ethical and legal obligation to provide care for employees who suffer harm as a result of their employment. This committee considers the government, with its management responsibility for military personnel, to be no different.

Although the law and associated regulations create a complex web of access to, provision of, and payment for health care, generally, the U.S. Department of Defense (DoD) provides medical care for active-duty personnel and retirees, whereas the U.S. Department of Veterans Affairs (VA) assumes the role for health care in certain circumstances after discharge from active duty. The current list of exceptions to complete coverage of health care responsibility, such as for the National Guard or the National Reserves when they are not actively deployed, is expected to grow as DoD moves to outsource much of its medical care and VA changes its eligibility criteria.

As a result, the locus of follow-up coordination—the focus of this chapter — is not uniform. The committee recognizes, with concern, that to actively ensure that the various government agencies provide appropriate care, including follow-up, for military personnel and veterans, a federal authority broader than that of either DoD or VA alone is required. A unified and comprehensive surveillance system that has access to and that uses preexposure and postdischarge outcome data is also necessary.

Some issues clearly affect the identification of long-term health effects. Some of these have already been discussed (e.g., good dosimetry and availability of records). A number of additional issues must also be recognized as important. For example, a bias may well occur when an active-duty soldier does not report an illness for fear of losing his or her military employment with a medical discharge. This will result in DoD assuming that there may not be a problem (or

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that it is small) when the problem is actually significant. On the other hand, once a person is discharged and a pension is available because of a disability, there may be a tendency to overreport and overestimate potential problems.

Throughout this report, the committee has raised the issues of measurement and recordkeeping. These activities are aimed at identifying potentially hazardous situations, preventing or limiting exposure, measuring and documenting exposure, providing information for diagnosis and treatment, and learning from experiences. In Chapter 2, the committee described the factors that are known to determine the type and magnitude of health effects of radiation, such as dose, tissue, and sex. The immediate psychological impact and the subsequent psychological and psychosomatic effects of having been at risk of or exposed to radiation have a different set of determinants that are incompletely understood. These effects are not unique to radiation and may also pertain to exposures to other toxic substances.

It is important to identify the postexposure effects associated with radiation for two distinct purposes: (1) to help the individual medically or in claims of the individual or family members for compensation and (2) to form the basis of knowledge that might be used to prevent future harms to others. In this chapter, the committee considers the follow-up of persons after a known or suspected exposure to ionizing radiation while in military service for (1) medical purposes and (2) epidemiologic purposes.

Medical follow-up is intended to assist the exposed individual directly. It involves one or more of the following actions, depending on the situation and the needs of the individual at a given time after a known or suspected exposure. In this chapter, the committee uses the following definitions with respect to prior known or suspected exposures to radiation:

- *medical assessment:* early postexposure basic health evaluation;
- *medical monitoring:* the screening of asymptomatic populations;
- *medical testing:* the testing of an individual when judged to be necessary by a clinician on the basis of a clinical examination, history, and risk factors; and
- *medical care:* the management of clinically apparent injuries, diseases, or conditions.

Although there may be a concurrent or future benefit to the individuals involved, the purpose of *epidemiologic follow-up* is to identify deviations from normal health parameters among defined groups of people over the short and the long term. Using defined populations—such as all personnel deployed to a particular military operation or a subset of personnel who had been at risk of exposure to a specific agent (e.g., radiation or a vaccine)—epidemiologists try to identify or confirm and quantify associations between exposure (e.g., radiation dose, deployment, and personal behaviors) and health outcomes (e.g., specific illnesses, causes of death, or health care use).

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MEDICAL FOLLOW-UP

Medical Assessment

Medical assessment may be defined generically as the early evaluation of an individual's basic health parameters in response to an acute health episode (e.g., severe chest pain or difficulty in breathing) or an unintentional exposure to a potential health hazard (e.g., a fall with a head injury or inhalation of toxic fumes). The purpose is to obtain data for comparison against previously recorded normal values for the individual or established norms for the general population and as a baseline against which the individual's future measurements can be evaluated for the assessment of progress. The assessment thereby provides a basis for diagnosing or ruling out acute conditions, patient management, establishing a prognosis, and future follow-up. Additional parameters are evaluated as indicated by the nature and circumstances of the exposure.

In the context of this report, medical assessment is defined as the evaluation of basic parameters of general and radiological health status after a known or suspected exposure to radiation or radioactive contaminants. Such an evaluation may be prompted by the development of nonspecific symptoms or trauma (e.g., nausea or blunt-instrument injury) or other detriments to an individual's performance during a military operation that carried a risk of exposure to radiation. Personnel are not likely to develop symptoms of acute radiation exposure at the dose range considered in this report (50 to 700 millisievert [mSv]); however, medical assessment is recommended after personnel exit areas of such potential exposure. The purpose of the assessment of asymptomatic individuals in these situations is (1) to rule out higher than expected doses, (2) to obtain baseline clinical data to assist in estimating the individual's radiation dose, and (3) to establish a basis for recommendations regarding the individual's need for medical care, periodic monitoring, or specific testing. This early postexposure assessment should be conducted by established protocols (Saenger, 1990; Voelz, 1990).

Medical Monitoring

Medical monitoring, as defined in this report, is systematic screening of a population of asymptomatic individuals for preclinical disease with the purpose of preventing or delaying the development and progression of chronic disease in those individuals. Medical monitoring differs from both medical care of existing conditions and follow-up for purposes of epidemiological evaluation.

As early as 1922, the American Medical Association endorsed routine physical examinations for the general population to reveal current and prevent future illnesses. This approach, along with the use of multiphasic testing, yielded little new information or served to confirm already diagnosed illnesses. Therefore, in 1983, the American Medical Association issued a policy statement with

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drawing its support for the standard adult physical examination. Canadian and Australian authorities have reached similar conclusions.

Similarly, medical monitoring after radiation exposure is not routinely suggested or practiced for individuals with known or suspected exposures to radiation. An exposure or a presumed exposure to radiation is not by itself sufficient to justify a medical monitoring program. The decision about whether a medical monitoring program is appropriate and necessary in a given situation should be based on consideration of a number of factors including a rigorous cost-benefit analysis. This analysis should take into account the following characteristics: (1) the exposure of concern (e.g., its certainty, dose, and temporal relationship of exposure to observation), (2) the disease of interest (e.g., its natural history and prevalence in the population), (3) the characteristics of the available screening tests (e.g., their effectiveness, sensitivity, and specificity), (4) the potential for the tests used to themselves cause harm; (5) the potential for action when test results are positive (e.g., the availability of and risks from follow-up evaluation), and (6) whether there is evidence that an intervention can improve the clinical outcome. In this report, the committee considers these and other issues of concern associated with medical monitoring programs in general and, specifically, as they relate to persons exposed to radiation.

Medical Monitoring for Delayed Deterministic and Stochastic Effects of Radiation

Because the effective dose range of interest for this report—50 to 700 mSv—is unlikely to cause delayed acute or chronic deterministic effects, the committee concentrates its discussion of medical monitoring or screening on malignant disease, which is the main long-term effect of radiation exposure.

Observations and research over the hundred years that radiation has been used and measured have identified certain malignant diseases that can be induced by radiation as well as by other known and unknown agents. Those malignant diseases that have been associated epidemiologically with prior radiation exposure are termed *radiogenic;* they include leukemia (all types except chronic lymphocytic leukemia); cancer of the female breast; cancers of the lung, stomach, thyroid, esophagus, small intestine, colon, liver, skeleton, central nervous system, and ovary; nonmelanoma skin cancer; non-Hodgkin's lymphoma; multiple myeloma; and cancer of the salivary glands (National Research Council, 1990). However, the government's approach to medical follow-up of potentially exposed individuals is based not only on scientific knowledge but also on the sociopolitical realities of veterans' concerns and congressional responses to them. Thus, it should be recognized that not all the health conditions identified as compensable under current laws and regulations have been associated scientifically with exposure to specific agents. Until September 1998, VA regulations

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(CFR, 1998d) identified 22 conditions as radiogenic; most, but not all, of them are malignant diseases. They are

- all forms of leukemia except chronic lymphocytic leukemia
- cancer of the thyroid, breast, lung, bone, liver, skin, esophagus, stomach, colon, pancreas, kidney, urinary bladder, ovaries, salivary gland, rectum, brain, and central nervous system; multiple myeloma; and lymphomas other than Hodgkin's disease;
- posterior subcapsular cataracts;
- nonmalignant thyroid nodular disease; and
- parathyroid adenomas.

Effective September 24, 1998, VA added both the broad category of "any other cancer" and the specific diagnosis of prostate cancer to this list of radiogenic conditions, despite the weakness of current scientific evidence for this conclusion. Under this regulation, any veteran who has a diagnosis of a disease identified in regulations as radiogenic and who can document a history of prior military exposure to radiation has access to VA medical care for the condition, provided that it clearly is not due to another (nonradiation) cause. This particular eligibility for care is not dependent on an officially adjudicated service-connected status. A more restricted list of radiogenic malignancies,* however, is defined in law for the designation of service-connection, which provides financial compensation and broader access to health care services (CFR, 1998c).

Separate from the consideration of government benefits, a number of investigators have discussed the principles for cancer screening in general. Taplin and Mandelson (1992) suggest a series of steps beginning with evaluation of the existing epidemiology literature in terms of the normal incidence of the disease of interest. It is not reasonable scientifically to screen for a disease that is extremely unlikely to occur as a result of a given exposure. If, for example, 100,000 people were exposed to a radiation dose that was estimated to increase the risk of developing cancer by one in a million, less than one additional case of cancer would be expected to result from that exposure. Screening of that population would not yield useful results. Screening is done for cervical cancer, which is diagnosed in 6 of 100,000 U.S. women annually, and for breast cancer, which is diagnosed in 85 of 100,000 U.S. women annually.

The justification for a proposed screening or monitoring program can be assessed by considering the normal incidence rates and comparing these to the

* Leukemia (other than chronic lymphocytic leukemia), cancer of the thyroid, cancer of the breast, cancer of the pharynx, cancer of the esophagus, cancer of the stomach, cancer of the small intestine, cancer of the pancreas, multiple myeloma, lymphomas (except Hodgkin's disease), cancer of the bile ducts, cancer of the gallbladder, primary liver cancer (except if cirrhosis or hepatitis B is indicated), cancer of the salivary gland, and cancer of the urinary tract (CFR, 1998c).

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excess number of cases expected as a result of some exposure. Consider the case of a disease that spontaneously occurs at an annual incidence of about 25 cases/100,000 population at age 50 but whose incidence rises to 50/100,000 at age 55. Excess cases induced by some toxic exposure would justify monitoring only if monitoring was also justified (and performed) for the increase (25 cases/100,000 population) that occurred spontaneously.

The latent period between radiation exposure and the development of a clinically detectable tumor may have an effect on the design of a screening program. In the case of military exposures, soldiers are usually between 20 and 40 years of age when they are exposed, and most radiation-induced tumors would be expected to begin to become clinical evident when they are older than age 40, and in most cases older than age 50. Since most cancers occur spontaneously at older ages, Berg (1991) has looked at cancer screening of a nonexposed general population over the age of 50. For such a population, he recommends periodic physical examination of the breast, mammography, a Pap test, physical examination of the skin, flexible sigmoidoscopy to 35 cm, and oral examination.

Recommended screening tests for cancer change with time as randomized clinical trials are completed and as technology develops. Probably the best comprehensive source of current information and guidance is the report of the U.S. Preventive Services Task Force (1996). It is of interest to note that most of the more than 50 screening interventions reviewed in the 1996 edition had insufficient evidence of effectiveness to warrant a U. S. Preventive Services Task Force recommendation.

Effects of Accuracy of Monitoring and Disease Prevalence

Since actions are taken or are not taken on the basis of screening test results, that false-positive and false-negative results can and do occur must be considered when planning a test program. The U.S. Agency for Toxic Substances and Disease Registry (ATSDR), which is charged by statute with evaluating the need for medical monitoring programs at Superfund Sites (sites subject to cleanup of hazardous materials, including radioactivity), has developed criteria for the establishment of medical monitoring. These are designed in recognition of the serious consequences that can result from both false-positive and false-negative test results. ATSDR has also addressed the psychological consequences of false-positive results.

The prevalence of the disease of interest in the population has an effect on screening test accuracy. When a test is performed with a symptomatic population, the prevalence of the expected disease is reasonably high. However, in the screening of an asymptomatic population, the probability that the disease is actually present is low. As an example, if the test is being used with a population of 10,000 persons with a disease prevalence of I in 10,000 and the test has a 5 percent false-positive rate, there will be 501 positive results, of which I will repre

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sent true disease and 500 will be false-positive results (a positive predictive value of 1/501, or 0.2 percent). The use of more than one test further reduces the positive predictive value. Even if the prevalence of disease in the screened population is quite high (e.g., 1 percent), the positive predictive value of a one test screening program rises only to 16 percent.

Assessment of the Benefit of Medical Monitoring

Even with the availability of an accurate test, there must be a demonstration of the benefit of early detection. There must also be a lead time during which a tumor can be found as a result of monitoring before symptoms occur. If the patient presents with symptoms at the same time that the test becomes positive, then periodic testing will be of no benefit.

The availability of a sensitive and accurate test that detects a tumor before symptoms occur still is not sufficient reason to justify the use of such a test to monitor the health of a population. There must also be an intervention or a therapy that is effective, available, and acceptable to the patient. A number of screening programs have found smaller tumors in high-risk populations (e.g., chest x rays of smokers), but the mortality rate was unchanged, probably because the tumor had already spread to distant sites in the body. As a result, chest x rays are not recommended for monitoring or screening even of smokers, who are at 5 to 10 times higher risk for lung cancer than nonsmokers.

Randomized trials using the screening tests must show a benefit. The benefit can be measured in a number of ways. Commonly used parameters are the percentage of people who are cured or the percentage of fatalities that are averted. More difficult to measure—and therefore less desirable as study endpoints—are a decrease in years of life lost or an increase in quality of life remaining.

Finally, effective use of a test depends on the clinician's sufficient understanding of the test to know the appropriate interval for repeat testing, as well as the costs and risks of the test.

Costs of Medical Monitoring

The International Agency for Research on Cancer (IARC, 1990) has pointed out that screening costs to be considered should include not only the financial cost of the initial medical actions but also the

- cost of intensive follow-up for false-positive results,
- emotional cost for false-positive results,
- cost of delayed diagnosis due to false-negative results,
- extension of period of morbidity for those in whom early detection does not improve survival,

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- unpleasantness of screening test (e.g., colonoscopy), and
- risk from screening (e.g., mammography).

An example of the major psychological costs (Wardle and Pope, 1992) associated with screening programs involves mammography. Mammography has rates of false positivity of 70 to 80 percent, so three of every four women who test positive must have a biopsy or surgery—with the accompanying physical risk and psychological fear—before they learn that they do not have a malignancy.

Monitoring Sensitive Populations

There are situations when risk is low (and monitoring the general population is not warranted) but a monitoring program might be justified for selected subgroups (Fearon, 1997; Perera, 1997). Such subgroups might include those who are genetically susceptible to a particular disease such as cancer. Relative to radiation exposure, the predominant general factor that appears to affect radiation sensitivity to a number of cancers is age at the time of exposure (with more risk per unit dose at the very much younger ages, which is not a factor for military personnel). Sex is also related to the incidence of cancer following radiation exposure: females have a slightly higher risk per unit dose than men due to the occurrence of breast and thyroid cancers.

At present, genetic testing is only beginning to be used, and its ramifications are not clear (Ponder, 1997). The issues of efficacy of intervention, test cost and accuracy, and disease prevalence considered throughout this chapter also apply to genetic testing. At present genetic testing is used only in the clinical management of families with well-defined inherited cancer syndromes.

Screening for Specific Cancers

Although certain types of leukemia and some cancers are generally accepted as having a scientific basis for their designation as "radiogenic cancers," to date screening programs have been shown to effectively reduce mortality only for cancers of the female breast and colon among this group of potentially radiogenic tumors. Although the Pap smear for the early detection of cervical cancer has proven to be highly successful in reducing the rate of mortality due to this cancer among women, the cancer's association with exposure to radiation is equivocal. The Pap smear is therefore unlikely to be useful for the detection of potentially radiogenic cervical cancers. The same may be said for prostate cancer, but prostate cancer is mentioned here because it has been added to regulations governing the VA's list of radiation-related conditions.

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Summary of Medical Monitoring Considerations

A medical monitoring program for asymptomatic persons exposed to radiation must take into account a wide variety of major factors before it is instituted. The major long-term effect that one might find after exposure to radiation in the dose range of 50 to 700 mSv is cancer. The risk of cancer is high even in nonexposed populations, and few tests have been shown to be of benefit in terms of improving either survival or quality of life. Those that have been endorsed include the Pap smear and mammography. However, the incidence of radiation-induced tumors among those exposed to the dose range of interest would almost always be less than the normal spontaneous incidence. If a monitoring or screening test is developed and an effective therapy is available, it is the spontaneous cancer risk (not the radiogenic cancer risk) that should drive a decision to do monitoring. It is theoretically possible that a test may be developed that could assess radiation-induced genetic damage likely to lead to malignancy. If such a test were developed it could prove useful. None of the above should prevent symptomatic persons from receiving appropriate diagnostic tests.

Medical Testing

Although a particular diagnostic test may not be indicated when it is applied to an asymptomatic group of persons, in select situations the value of the test can be improved significantly in terms of specificity and sensitivity by clinical examination, history, and evaluation of risk factors. A familiar example is that of testing for human immunodeficiency virus (HIV) infection. It is unreasonable to test the general population for HIV. It would be useful, however, to test an asymptomatic medical worker who was stuck with a needle that had been used on a patient diagnosed with AIDS. All of these situations need to be assessed individually.

The radiation situation is more complex, but examples can be given. If a 35-year-old female presented with a solid palpable lump in her breast and the examining physician knew that she had received a high radiation dose in a military operation, a mammogram or an aspiration needle biopsy may be ordered. Without the high-dose radiation history, the physician may have elected to do an ultrasound or wait and not do any diagnostic procedure. If the clinical information was that the lump appeared within 5 years of the radiation exposure, the physician would also not have ordered the tests since the risk of radiogenic breast cancer is very small or zero at only 5 years since the exposure.

On the basis of the risk from the dose range considered in this report (50 to 700 mSv) and the lack of effective screening tests for neoplasms such as leukemia, radiation exposure should not play a significant role in the decision to test individuals.

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Medical Care

Medical care following exposure to ionizing radiation concerns the management of the early and delayed deterministic effects resulting from doses above threshold levels, such as radiation-induced injuries to skin and bone marrow depression, and the management of stochastic effects, primarily nonspecific tumors that may become clinically evident years after exposure to radiation (see Chapter 2). With the dose range that the committee is considering, the greatest risk is of the appearance of benign and malignant tumors years later. However. because of the uncertainty of the dose that may be encountered in hostile situations, brief consideration of the deterministic effects that will appear within months of certain types of acute exposures to radiation above the threshold levels is required.

Medical Care for Early and Delayed Deterministic Effects

As described in Chapter 2, it is unlikely that symptoms of deterministic effects will appear in the absence of acute whole- or partial-body doses of less than I Sv (100 rem) of penetrating radiation. Early evidence of acute radiation-induced cellular injury, for example, structural changes in the chromosomes of some circulating lymphocytes, and falls in the absolute lymphocyte and sperm counts, is, however, clinically detectable in asymptomatic individuals who received lower doses.

Examples of scenarios in which soldiers may become involved with a risk of exposure to radiation within the 50- to 700-mSv range include (1) responding to a nuclear reactor accident, (2) securing a negligently or deliberately abandoned sealed radiation source, or (3) containing radioactive materials exposed to the environment, as may occur if a nuclear waste dump is disturbed. Such events could occur in the course of normal peacetime duty on friendly territory, on hostile or nonhostile peacekeeping missions, or as the result of terrorist actions. In these instances, exposures may be acute or chronic, they may involve nonuniform irradiation resulting in high doses to specific areas of the body, they may occur alone or with radioactive contamination, and they may occur with or without trauma or other injuries or illnesses.

In evaluating the effects on health of radiation released by the detonation of nuclear weapons or the dispersion of nuclear materials, DoD has concentrated its preparedness planning and extensive research efforts on the acute deterministic effects of radiation, including the acute radiation syndrome and the associated bone marrow depression. Events in which these types of radiation-induced injuries have occurred have been documented and reviewed extensively and have been presented together with the current recommendations for evaluation, medical care, and follow-up of exposed individuals (Mettler et al., 1990; Reeves et al., 1998).

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Expression of acute radiation injury in some cell systems is delayed for weeks or months after an acute exposure to penetrating radiation above threshold levels (see Chapter 2). A period of transient male infertility may follow exposure to doses beginning at the upper end of the 50- to 700-mSv range. After higher but sublethal whole-body doses, males will experience a low sperm count with a nadir at about 45 days postexposure or an absence of sperm postexposure for a period that is directly proportional to the dose. Females may experience a period of amenorrhea after acute radiation exposure. Several sievert to the gonads are required to cause permanent sterility in previously fertile males and females of reproductive age; thus, sterility will not be a problem for individuals at risk of doses in the 50- to 700-mSv range (IOM, 1995). The threshold doses for the typically delayed (for weeks or months) expression of acute radiation injury to other tissues—such as the endothelial cells lining the blood vessels and connective tissue and their replacement by fibrous tissue (i.e., fibroatrophy), the optic lens (cataract), and the thyroid gland (thyroid hypofunction)—also are considerably higher than the range of the 50 to 700 mSv that is of interest for this report; thus, there will be no indication for specific medical care for soldiers with such exposures.

Medical Care for Stochastic Effects

As noted previously, the primary stochastic or late effect of exposure to radiation is the development of radiation-induced tumors of types that are not caused only by exposure to radiation; they may be benign or malignant. It is assumed that the probability that such tumors will become clinically evident among a population some years after exposure to radiation above background levels is directly related to the dose. Their occurrence in an exposed population may be observed as an increase in the rates of occurrence of specific tumors above the rate for the spontaneous occurrence of tumors among the nonexposed population, beginning at ages at which the rate of occurrence of spontaneous tumors begins to increase. Radiation-induced or radiogenic tumors are histologically and clinically indistinguishable from spontaneously occurring tumors. Their diagnosis, treatment, and management are the same as those for spontaneously occurring cancers of the same type.

Ethical and Legal Considerations: Follow-Up Programs

When the military knows that its soldiers have been or might have been exposed to agents that could produce long-term effects, it has an ethical obligation to notify them of this fact and to inform them of any new information concerning their exposure or ways to minimize its health effects. Once the military complies with these two obligations, an ethically responsible follow-up program would

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provide for reasonable health screening to try to detect damage, and if an effective treatment is available, that treatment should be provided as well. If medical monitoring would be of net benefit, it should be done. However, the committee agrees that routine monitoring programs established specifically for persons with known or suspected exposure to radiation would not be useful at this time, given the limitations of current cancer screening programs. The follow-up obligation is directly applicable to soldiers who were at risk of exposure, and for whom the increased risk of long-term adverse health effects is known or reasonably suspected. There is no legal or ethical obligation to follow-up nonexposed soldiers for exposure-related health effects since there is no reason to assume they would be at special risk of harm.

In those instances when government-initiated follow-up is appropriate, the current organization of health care services in the United States significantly complicates adequate follow-up. In recent years, only about 10 percent of current veterans receive care from VA, in part because of eligibility requirements and access to other sources of care. Were the government to uncover information that would be of interest or of importance to veterans, how would it communicate this to the relevant veterans? The Departments of Defense, Veterans Affairs, and others with related responsibilities may want to develop policies and procedures to govern proactive contact of veterans. These might cover logistics and ethical issues such as consent and secondary uses of available data.

EPIDEMIOLOGIC FOLLOW-UP

Description and Rationale

All the medical follow-up processes described in the preceding sections involve direct contact with *individuals* who may have been exposed to radiation. Epidemiologic follow-up is based primarily on the *records* for *groups* of those individuals. Epidemiologic studies seek to identify the distribution and determinants of disease among human populations by comparing groups that have some experience or exposure, such as radiation, in common. Although such research may benefit the individuals studied, it contributes primarily by increasing scientific understanding of the relationships between exposure and subsequent health outcomes.

Epidemiologic follow-up of a group of persons known or presumed to have been exposed to a potentially hazardous agent may be implemented to

- identify adverse health effects in an *at-risk* group and to determine whether the risk of such effects is greater than that for a comparable but nonexposed group of individuals,
- determine whether the increased risks that may be identified are associated statistically with the exposure,

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- determine whether the increased observed risk is related to or influenced by other factors associated with or independent of the exposure, such as tobacco smoking and radon, and
- add to the scientific knowledge base, which can then be used to derive and refine risk estimates and to develop interventions.

In the circumstances considered in this report, base and field commanders could use the information obtained from epidemiologic follow-up studies to weigh the costs of different potential exposure scenarios.

Epidemiologic follow-up studies may describe a disease situation in a defined group at a specific point in time (cross-sectional prevalence studies) or may collect information about group members over an extended time period (longitudinal studies). In prospective longitudinal studies, a defined population (or cohort) that has a common experience or exposure is followed forward in time to determine if there is an increased risk of disease among this cohort relative to that among a comparable nonexposed cohort. Alternatively, groups of individuals with and without a specific disease, condition, or cause of death can be compared retrospectively, using recorded data, to determine if the risk of exposure was greater in the diseased than in the nondiseased group.

Issues of Study Design

The planning and implementation of epidemiologic research involve many practical concerns (IOM, 1995), including the

- availability of a clearly defined and appropriate study population with unique individual identifiers;
- size and composition of the study population;
- completeness (and lack of bias) with which study subjects can be enrolled;
- magnitude and distribution of exposure to the hazard being studied;
- accuracy—including the unbiased collection of data and adherence to a defined time frame—with which the exposure can be measured (measurement of absorbed dose, as in the atomic bomb survivors, is extremely important since the most compelling evidence of causality is the demonstration of a dose-response relationship);
- accuracy—including the unbiased collection of data and adherence to a defined time frame—of disease identification (history of disease should be confirmed from hospital records, and causes of death should be determined by obtaining copies of death certificates);
- background rate of the disease being studied;
- expected increase in the incidence of disease among the exposed group;
- availability of information on other factors that might determine disease; and

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- procedures to ensure valid consent for those research settings in which it is appropriate.

Choice of Population and Outcome to be Studied

An epidemiologic follow-up study typically begins by identifying two groups of people—those exposed and those unexposed to the agent, treatment, or characteristic being studied—and then seeks to determine whether the groups experience different health outcomes. The choice of an outcome—the measure of health—affects study design, complexity, and feasibility.

Mortality is the outcome most conducive to an epidemiologic study because the occurrence is clearly definable, happens at most once per person, and relatively complete records are available. Mortality is not, however, always the health outcome of interest. Many questions involve diseases and conditions that affect the quality of life but that do not kill the individual. Physical and emotional health are often grouped under morbidity, yet concomitant employment, economic, and social well-being outcomes are increasingly being used as measures of effect. Finally, although not a direct measure of an individual's health, health care use—and its cost to the individual, the military, and other government agencies—is a reasonable choice of outcome for some epidemiologic follow-up studies. The study of each of these outcomes—death, illness, and cost— poses substantial challenges to the epidemiologist.

Data Sources and Quality

A robust study design includes a clearly defined and identified study population and assurances that adequate data (in terms of completeness and lack of bias) regarding those individuals can be acquired. All of the products of the exposure monitoring and recordkeeping activities that the committee discussed in earlier chapters of this report are available for use in epidemiologic follow-up studies. Assessing whether and to what extent potentially hazardous exposures (e.g., ionizing radiation) are present is complicated by the demanding conditions arising from the hazard itself, as well as by limitations associated with the devices used to quantify the exposure. Problems specific to the measurement of radiation exposure are discussed in Chapter 2 of this report. The quality of the exposure data tremendously influences the feasibility and usefulness of such studies.

In part because of the very limited existence of prospectively designed and funded epidemiologic studies, researchers often turn to available databases. Administrative databases and registries are prime examples. They can be very useful in the consideration of some questions, but they have severe limitations in many epidemiologic applications.

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Because of the need for unbiased sample selection and exposure and outcome measurements, it is a great advantage for epidemiologists to chose the population to be studied and to measure prospectively the baseline characteristics (demographic, clinical, and risk factors) of the individuals in that population. Also, outcome information must be sought in ways that make all members of the population equally likely to be identified. Registry data are therefore not necessarily well-suited for use in epidemiologic analyses. The drawbacks of registry data include the following: (1) the individuals with adverse outcomes may be more likely to register; (2) even among those with adverse outcomes, only a subset will register; (3) the outcome is influenced by more than the putative exposure, and those confounding factors—such as access to medical care (diagnosis and treatment) or health-related behaviors such as tobacco use—are usually not recorded in registry databases; and (4) reports to registries are often associated with compensation claims.

Confounding factors, including disease-causing behaviors such as smoking and alcoholism, may obscure the relationship under study. This often is exacerbated when studies begin many years after the occurrence of an exposure and require many years to complete.

Measurement of exposures, outcomes, and possible confounding factors is further complicated by the availability and quality of event records (e.g., medical and dose records). Records may be poorly maintained, stored in decentralized locations, or discarded after a set time period. For example, in conducting a mortality study of military participants in Operation CROSSROADS, a nuclear test series done in 1946, researchers (Johnson et al., 1996) required records maintained by the VA's health and benefits components; DoD ship logs and morning reports, which are now stored in paper files in cartons at numerous facilities of the National Archives and Records Administration; National Personnel Records Center in St. Louis, Missouri (Army and Air Force records in that facility sustained heavy damage in a 1973 fire); vital records departments in 50 states and additional territories; and the National Center for Health Statistics National Death Index; among others. Record systems may also inconsistently document events in situations in which examiners, such as pathologists and physicians, do not use standardized diagnostic routines.

A major consideration in the design of a study and the analysis and interpretation of its data is statistical power. To determine whether there is a difference in outcome between an exposed and an unexposed population, each population must be large enough (sample size) so that normal variation does not dwarf any real differences. That sample size is determined by the prevalence of the outcome in the unexposed population and the level of uncertainty that the researcher is willing to take in terms of false-negative results (not finding an exposure-outcome relationship in the data when there actually is one).

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Military and Radiation-Specific Study Design Issues

Attempts to study the late health effects of exposure to radiation—assuming that malignant disease is the major concern—include other specific difficulties:

- no unique disease: all malignancies are pathological and clinically the same regardless of cause;
- population size and dose need to be large enough to be able to detect a statistically significant difference in risk between exposed and nonexposed populations;
- long interval between time of exposure to and occurrence of disease (latent period);
- dose uncertainties that may overwhelm the true dose at low dose levels; and
- confounding factors that may mask a radiation effect if there is one.

A complicating factor in studies of military-related exposures is that the authorities of the involved government agencies overlap. DoD and VA, along with the Department of Health and Human Services,* have some common responsibilities for the health of veterans. Federal legislation and the budget process, however, leave each of these agencies without the authority or funding to perform other necessary activities in support of veterans' health. Because ascertainment of health outcomes must be equally likely for all individuals in a study, this diffuse authority for follow-up can affect an epidemiologic study's time line, expense, complexity, and, ultimately, validity.

DoD and VA are steadily improving their automated records systems to allow sufficient follow-up over time. These will be a valuable source of data for those service members and veterans who seek all of their health care through those agencies. Most veterans, however, do not go to VA for health care, and those who do are predominantly those who have service-connected disabilities or who are eligible for coverage because of low income. Hence, any study findings limited to VA health care databases could not easily be generalized beyond those groups. Furthermore, it may be that both service members and veterans seek care for personally sensitive health care needs outside of the government systems for privacy reasons.

Administrative obstacles arise because a single agency is not responsible for all care provided by or paid for by the government. This relates to the choice of study population, which was mentioned earlier. An epidemiologic follow-up study poses a question and attempts to answer it by using data from the study

* The U.S. Department of Health and Human Services administers the Medicare and Medicaid programs, the National Center for Health Statistics, and the National Institutes of Health, as well as other programs relevant to the health of the population, including veterans.

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population. Study cohorts that have been selected according to different sets of criteria may yield different answers to the study question. Examples of different study populations include veterans (or their records) who actively respond to active VA or DoD requests for volunteers, veterans whom VA or DoD identifies passively through administrative records, and scientifically designed samples or groups of veterans with either a common exposure or a common adverse health outcome who are systematically followed for appropriate data collection.

Ethical Issues

Epidemiologic studies necessitate consideration of the privacy and confidentiality concerns associated with the use of personal records. Privacy refers to keeping sensitive information about oneself secret. Confidentiality refers more generally to keeping personal data from being used by others without informed consent (IOM, 1995). In the United States, federally mandated institutional review boards (IRBs) serve to ensure that researchers take adequate steps to preserve the confidentiality of the data they collect, requiring that they specify who will have access to the data, how and at what point in the research personal information will be separated from the data, and whether the data will be retained at the conclusion of the study. IRB reviewers also make sure that the informed consent of the subjects will be obtained before interviews are conducted (Wallace [1982] and OPRR [1993], as cited in IOM [1995, p. 20]).

There are two types of epidemiologic investigations. One is an *experiment,* in which the researcher exposes one group of individuals to a hazard or a vaccine and does not expose another group and then measures and compares the outcome in both groups. The other type of epidemiologic research is an *observational study,* in which researchers use data that are available from an operationally caused exposure not planned or influenced by the researchers. Both of these investigations require IRB approval. Different ethical rules may apply for certain kinds of observational studies, when, for example, anonymous or unidentifiable data are used. Whether adhering to the "common rule" or developing its own policies and procedures, the Army should follow ethically appropriate rules in all research. Despite the specialized context of military service, set privacy and confidentiality protections should be maintained.

Examples of Epidemiologic Studies of Military Exposures

The Institute of Medicine's Medical Follow-up Agency (MFUA) has evaluated a number of military veteran populations for potential late health effects as a result of exposures during military service. These include a published study of the mortality of veterans who participated in Operation CROSSROADS in 1946, the first postwar U.S. atmospheric test of nuclear weapons (Johnson et al., 1996),

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and a study, which is now underway, of participants at five other test series in the 1950s.

In considering moving beyond mortality endpoints in studies of Atomic Veterans, MFUA convened an expert committee to explore the feasibility and potential design of studies of reproductive outcomes, a concern of many veterans. That committee's report (IOM, 1995) stated that it will be extremely difficult, if not impossible, to find and contact a sufficiently high and representative percentage of veterans' families, to establish a good measure of dose for each veteran, to identify and accurately document reproductive problems that occurred over a 50-year interval, and to measure other factors that cause reproductive problems and therefore might confound any observed relationship between radiation exposure and reproductive problems (IOM, 1995, p. 79).

PSYCHOLOGICAL EFFECTS AND THEIR MANAGEMENT

In addition to the physical effect of radiation on tissue, psychological effects occur following real or perceived radiation exposure, and these have been studied in a number of populations (IAC, 1991). Most of these studies, such as those concerning Chernobyl, have been related to accidental exposures. Numerous other studies relate to both the measurement and the perception of risk in general (National Research Council, 1996). In this brief section of its report, the committee raises the issue of psychological effects, including stress; this report is not the setting for a complete discussion of the complex components of that subject.

Usually, the perception of the risk from radiation exposure is much greater than the actual risks described in the scientific literature. Much of the concern about radiation exposure is because of its unfamiliarity, the fact that it is related to a dreaded illness (cancer), and, depending upon the situation, the fact that exposure is nonvoluntary. Media coverage of exposure situations can amplify the psychological effects. When, for example, the media report exaggerated or false claims, the potentially exposed population becomes even more worried than they were initially, resulting in even greater media attention (Lee, 1996).

Since the accident at Chernobyl the psychological effects of the accident have been studied quite extensively. In a paper presented at the 1996 International Atomic Energy Agency Conference "One Decade After Chernobyl: Summing up the Consequences of the Accident," Lee writes that "[T]he main human legacy of the accident has been anxiety about health and a social disruption that has manifested in widespread health disorders not induced by radiation" (Lee, 1996, p. 285). The accident presented an unfortunate but unique test situation. Hundreds of villages were exposed to fallout, with the absorbed doses being at the lower end of those considered in this report (about 50 mSv). Due to the nonuniform nature of the atmospheric dispersion of the radioactivity, however, interspersed among those exposed villages were many villages that were not exposed to radiation. Although the two populations were significantly different in terms

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of stress and anxiety, the absolute levels of stress and anxiety were high in both populations compared to what would be expected in general populations. Persons residing in unexposed villages reported a very high incidence of health complaints that they believed to result from the radiation exposure. For example, 45 percent of the people in contaminated villages indicated that they were sure they had an illness due to radiation, whereas 30 percent of persons in clean villages reported illnesses due to radiation (Lee [1996] describing an unpublished report by Drottz-Sjoberg et al. [1994]). Thus, a severe obstacle in studying health effects in Chernobyl was the lack of a clear definition of either contaminated areas versus noncontaminated areas or exposed persons versus nonexposed persons.

Initial reports from the former Soviet Union described a number of ill-defined entities including radiophobia, chronic radiation sickness, and vegetative dystonia (IAC, 1991). There was also the issue of whether these persons suffered from posttraumatic stress disorder (PTSD). PTSD is usually the result of witnessing a sudden catastrophic event (e.g., a battle, earthquake, or fire) that is over in a short period of time. It is manifested by intrusive recollections of the event and avoidance symptoms. Although Chernobyl firemen may have had PTSD, persons distant from the accident had symptoms inconsistent with the diagnostic criteria for PTSD, leading Lee (Lee, 1996) and others to propose a related but distinct entity—chronic environmental stress disorder.

Although the factors contributing to symptoms are complex (e.g., food restrictions, relocation, and financial incentives), the major international psychological studies invoke chronic environmental stress as the major etiology of these reported symptoms (IAC, 1991). Stress can generally be defined as adverse mental experiences that have negative effects on bodily functions; it can be measured by physiological indices (Lee, 1996).

Delayed and incomplete transfer of information from responsible authorities to potentially exposed persons has been a major cause of psychological stress in many radiation exposure situations (Lee, 1996). Transfer of information on the extent and magnitude of the risk or potential risks should occur before persons are exposed, but if this is not practical (as sometimes occurs in accidents or military situations) it should be done as soon as possible, depending on the nature of the circumstance (mission).

Stress can be alleviated in a number of ways (Lee, 1996). A straightforward strategy is to remove the stressor (e.g., decontaminate the area). This, however, is of little help to people who have already been exposed to radiation. A second alternative is to increase people's sense of control. This may include the implementation of specific medical procedures to help eliminate internally deposited radioactive materials, the institution of voluntary food controls, or the formation of community action groups. The third way to alleviate stress is diffusion of knowledge that changes the way that the radiation source and risks are perceived. This is important not only for the exposed persons and their families but also for the medical community, media, and other groups that are involved.

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Particular attention should be paid not only to relieving the stress of the individuals involved but also to the social task of reestablishing support and mutual understanding between individuals. The social stigmatization of exposed persons—such as after the atomic bombings of Hiroshima and Nagasaki as well as after Chernobyl—results in prejudice and cuts off social contact and communication (Lee, 1996).

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Recommendations

The U.S. Army Surgeon General requested guidance from the Institute of Medicine Committee on Battlefield Radiation Exposure Criteria on the management of military operations in which exposures to effective doses of radiation in a range of up to 700 millisievert occur. The committee has formulated recommendations that cover a number of areas. Some of these areas have already been addressed by the military but are included here because they are important and the report would not be complete without their consideration.

BALANCING FUTURE AND PRESENT HARM

Current doctrine and risk evaluation by military commanders focus on numbers of acute injuries and fatalities and on those factors that may affect the ability to achieve a military objective. The U.S. Department of Veterans Affairs deals with long-term health effects and disability. A focus on the acute effects from any cause is still largely appropriate for hostile situations, but it discounts or ignores long-term detriment and is inappropriate for less emergent situations in which the military may be asked to participate.

The Army asked the committee to consider exposure to doses of less than 700 mSv. Although no significant acute effects are expected to result from such radiation doses, excess risks of many types of cancer and leukemia have statistically significant associations with doses in this range. Although the long-term effects of radiation are relatively well known, the long-term detriment associated with other exposures or potential exposures, such as psychological stress, are less well understood and quantified. The committee thinks that these should not be ignored.

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Recommendation 1: When making decisions, commanders should consider the long-term health effects that any action may have on their troops.

- This should become standard operating policy.
- In addition, the U.S. Department of Defense should attempt to quantify long-term detriments from a number of causes, including radiation, and develop training materials and scenarios that address these effects.
- The long-term effects to be considered when making operational decisions should include not only those from radiation but also those from conventional injuries, chemical and biological agents, and psychological stress.

PHILOSOPHY OF RADIATION PROTECTION

A philosophy for dealing with any potential harm should be clearly stated, widely disseminated, ethically based, practical, and comprehensive. This will allow commanders to make informed decisions and be flexible rather than having to deal with prescribed limits when they may be inappropriate or impractical. This philosophy should be focused on minimizing the risk of harm while allowing the performance of the required military objective. Radiation exposure is clearly justified in some situations because the risk of radiation-induced harm is less than the risks from other hazards associated with the action. A policy that completely avoids radiation exposure is inappropriate and may expose troops, and perhaps others, to greater risks of harm from other, nonradiation, causes.

Recommendation 2: The U.S. Department of Defense should develop and clearly express an underlying philosophy for radiation protection.

A. The committee suggests application and adaptation of the system recommended by the International Commission on Radiological Protection.

- This system includes practices as well as interventions.
- These are required to be initially justified (more benefit than risk) and then optimized (dose minimized) in the context of the situation.

B. The committee recommends that in peacetime or nonemergent situations, soldiers should be accorded the same level of protection accorded civilians.

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- Those soldiers who may be exposed to radiation dose levels similar to those to which civilian radiation workers are exposed should have the same level of training as civilian radiation workers and should be subject to occupational dose limits.

C. In settings in which an intervention is required and specific numerical dose limits are neither applicable nor practical, the committee recommends that commanders justify the mission (there is more benefit than risk), examine competing risks, and optimize the mission (identify ways to minimize dose without jeopardizing the mission).

- Examples of these settings include emergent or lifesaving actions, actions to prevent exposure of large populations, and hostile situations.

COMMUNICATING RISK

Training and risk communication are extremely important not only so the troops can adequately achieve their objective but also so they can understand the risks and can protect themselves.

Recommendation 3: Military personnel should receive appropriate training in both radiation effects and protection. Their training will need to vary on the basis of the particular level of potential exposure and the task at hand.

- Training may range from task-specific operational briefings to full courses, depending on the situation.
- Well-crafted, realistic scenarios should be incorporated into training at all levels.
- Potential long-term health consequences from radiation exposure should be included in the discussion of risks.
- The training should put radiation effects in perspective in language that the troops can understand but not in a way that inappropriately minimizes the effects or creates unwarranted fear.
- When long-term risks of harm from sources other than radiation are largely unknown, this should be stated.
- Regardless of current North Atlantic Treaty Organization policy, the U.S. Department of Defense should avoid using the terms *low risk* or *no risk* in training and briefings when radiation levels clearly carry a measurable cancer risk.

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RADIATION DOSIMETRY, RECORDS, AND REPORTING

For risk management during and after a mission, it is important to estimate or quantify current and past exposures. This is optimally done through the use of radiation detection devices, environmental sampling, personnel dosimeters, bioassays, and, possibly, whole-body counting. Even in certain hostile situations when all of these may not be possible, estimates of exposure conditions and dose can still be made. Such information should be available to military personnel during active duty and after discharge.

Recommendation 4: A program of measurement, recording, maintenance, and use of dosimetry and exposure information is essential.

A. Troops expected to be in areas where there is a risk of radiation exposure should have individual dosimeters.

B. Systematic individual radiation dose records—external and internal doses—should be maintained and should follow the soldier from one operational unit to another.

C. A system that includes the capability to field monitor, and estimate or measure and then record internal doses needs to be developed.

- When appropriate, organ-absorbed doses should be recorded in addition to the effective dose.

D. The U.S. Department of Defense should also maintain exposure records in a confidential manner that contains strong privacy assurances. Records should be kept in a secure form and should be available to the individual.

E. Annually and upon deactivation or discharge, potentially exposed military personnel should be given a written record of their radiation exposures with estimated doses (annual and cumulative), even if they are zero.

- This should be separate from any administratively required occupational recording and notification.
- There should also be an explanation of the implications of these radiation exposures for future health outcomes.
- Even if an operation is classified, there is still a need to provide such information.

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FOLLOW-UP

The exposure of troops to agents and situations that may have long-term health effects raises the issue of whether there is any appropriate medical monitoring (screening) that will detect such effects before they are evident clinically and that may positively affect disease progression or outcome. The primary effect in the cumulative radiation dose range that the committee considers in this report is an excess risk of certain types of cancer and leukemia. Unfortunately, at this time only a few screening tests are clearly effective; these tests are used to detect breast, cervical, and colon cancers. Physician-directed individual diagnostic testing may be useful in selected situations, particularly when radiation absorbed doses are extremely high. It should be noted that cancer occurs in about 40 percent of the U.S. population (NCI, 1994). For doses in the highest dose range addressed in this report (500-700 mSv), the increased risk of cancer attributable to the radiation dose is about 1/10 the normal baseline incidence rate for unexposed individuals. Although this is a low percentage, a large number of troops exposed at these doses could result in a large number of excess cancers.

Recommendation 5: Given the tests that are currently available, and their limitations, testing and monitoring programs for cancer (whether spontaneous or radiogenic) should be limited to those testing and monitoring programs included in guidelines for the general population.

- Specific periodic screening or medical monitoring of radiation exposed populations is not warranted solely on the basis of radiation exposure in the dose range considered in this report.
- If effective tests for other cancer types do become available, screening may be useful on the basis of the normal cancer incidence in the general population.
- For persons who have received cumulative effective doses in excess of 50 mSv, the establishment of well-designed and dynamic registries may be helpful in addressing future health-related issues on an individual or population basis.

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Appendix A

The ACE Directive

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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.

(c). 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

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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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NATO UNCLASSIFIED

AD 80-63

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.

A-1

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Appendix B

Participants in Committee Meetings and Workshop

January 31,1997 Meeting

LTC Carl Curling

NBC Defense Staff Officer, Health Care Operations Directorate, Army Surgeon General's Office

LTC John Bliss

International Chairman, NATO Working Group 2 on Low-Level Radiation

COL David Jarrett

Director, Military Medical Operations Office

Armed Forces Radiobiology Research Institute

CPT Marc Umeno

Nuclear Medical Science Officer

U.S. Army Nuclear and Chemical Agency

MAJ Debra Schnelle

Manager, Medical Health Physics Program

U.S. Army Center for Health Promotion and Preventive Medicine

MAJ Brett Armstrong

Chief, Nuclear, Biological, and Chemical Sciences Branch

U.S. Army Medical Department Center and School

CAPT Richard LaFontaine

Radiation Health Branch, Navy Bureau of Medicine

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LCDR Phillip Liotta
Health Physics Program Manager, Headquarters, Marine Corps (BUMED)

October 9,1997 Meeting

LTC Charles Allison
Dept. of Army, DDCSOPS and Space and Special Weapons Division (DAMO-SSD)

LTC John L. Bliss
Was Chair, NATO Working Group 2 on Low-Level Radiation
Now at Uniformed Services University Health Sciences

LTC Carl Curling
NBC Defense Staff Officer, Health Care Operations Directorate, Army Surgeon General's Office
Head, delegation for the U.S. NATO NBC Medical Working Party
Medical representative, delegation to NATO Working Group 2 on Low-Level Radiation

Dr. Charles N. Davidson
Director, U.S. Army Nuclear Chemical Agency (USANCA)
Chair, U.S. Delegation to NATO Working Group 2

LTC Robert Eng
Center for Health Promotion and Preventive Medicine

COL Benedict M. Diniega
Sr. Clinical Consultant, Directorate of Combat Development, AMEDD Center and School
Member, delegation to the NATO Medical NBC Working Party

CDR Greg Gorsuch
BUMED

COL David Jarrett
Military Medical Operations, Armed Forces Radiobiology Research Institute

LTC Don Jordan
Air Force Surgeon General's Office

Scott Kaeppel
USACHPPM, Henry M. Jackson Foundation contractor

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CAPT Richard LaFontaine
Radiation Health Branch, Navy Bureau of Medicine
LCDR Philip Liotta
Health Physics Program Manager, Headquarters, Marine Corps (BUMED)
MAJ Gary J. Matcek
Health physicist, retired from Public Health Service
Contractual services to USACHPPM
CPT Chad McKee
Medical Health Physics Program, USACHPPM
MAJ Debra D. Schnelle
U.S. Army Center for Health Promotion and Preventive Medicine Command
Michael S. Terpilak
USACHPPM, Henry M. Jackson contractor
Dr. Robert Young
Retired from Defense Nuclear Agency

February 2,1998 Workshop

William J. Brady
Health physicist (accompanying Ms. Broudy)
William E. Brew
Director Intergovernmental Relations, Alliance for Aging Research
Pat Broudy
Legislative Director, National Association of Atomic Veterans
Robert L. Campbell
Executive Director, Trinity Post
CPT Douglas Carr
Mobilization Division, DCSOPS, U.S. Total Army Personnel Command
Richard Fuller [Could not attend.]
Director of Legislative Affairs, Paralyzed Veterans of America
COL Fred Gerber
Director, Health Care Operations, Army Surgeon General's Office

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David Gorman [Could not attend.]
National Adjutant, Disabled American Veterans
Susan Mather, M.D., M.P.H.
Chief, Public Health and Environmental Hazards
Veterans Health Administration, Department of Veterans Affairs
Caroll McBrine, M.D.
Veterans Benefits Administration, Department of Veterans Affairs
Fran Murphy, M.D.
Director, Environmental Agents Service
Veterans Health Administration, Department of Veterans Affairs
MAJ Robert Nang
Program Manager, Disease and Injury Control Policy
U.S. Army Center for Health Promotion and Preventive Medicine
Neil Otchin, M.D.
Program Chief for Clinical Matters,
Office of Public Health and Environmental Hazards, Dept. of Veterans Affairs
LTC Paul Smith
Director of Clinical Preventive Medicine
US Army Center for Health Promotion and Preventive Medicine
MAJ Rob Syvertson
Office of the Army Surgeon General
CAPT David Trump
Clinical Services, Health Affairs, Department of Defense
Coleen Weese, M.D.
U.S. Army Center for Health Promotion and Preventive Medicine
Craigenne A. Williams
Board Member, National Association of Atomic Veterans
Dr. Robert J. Williams
National Association of Atomic Veterans

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Appendix C

Biographical Summaries

COMMITTEE MEMBERS

FRED A. METTLER, JR., M.D., M.P.H. *(Chairman),* is professor and chairman of the Department of Radiology at the University of New Mexico Health Sciences Center in Albuquerque, New Mexico. His area of expertise is medical effects of ionizing radiation. He is the United States representative to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), a commissioner of the International Commission on Radiological Protection (ICRP), and a scientific vice-president of the National Council on Radiation Protection and Measurements (NCRP). Dr. Mettler has served as a consultant to the Peace Corps, the World Health Organization, and the International Atomic Energy Agency and was the Health Effects Team Leader for the International Chernobyl Project.

JOHN F. AHEARNE, Ph.D., is currently Director of the Sigma Xi Center; Adjunct Scholar, Resources for the Future; and Adjunct Professor of Civil and Environmental Engineering and Lecturer in Public Policy, Duke University. He has served as Executive Director for Sigma Xi, the Scientific Research Society; Vice President and Senior Fellow for Resources for the Future; Commissioner and Chairman of the U.S. Nuclear Regulatory Commission; and held numerous positions within the Department of Defense and the Department of Energy. He chaired the National Research Council Committee on the Environmental Management Science Program, chairs the Committee to Review the Research Activities Completed Under the Energy Policy Act of 1992 (EPACT), has served on many other NRC committees, and is a member of the Board on Radioactive Waste Management. Dr. Ahearne received a bachelor's degree in engineering physics and an M.S. in physics from Cornell University, and an M.A. and Ph.D. in physics from Princeton. He is a member of the National Academy of Engi

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neering, Society for Risk Analysis, and American Nuclear Society and a fellow of the American Physical Society, American Academy of Arts and Sciences, and the AAAS.

GEORGE J. ANNAS, J.D., M.P.H., is professor and chair, Health Law Department, Boston University School of Public Health, and professor at Boston University Medical School and Boston University Law School. He is the cochair of the Committee on Medical Practice and Medical Research of the American Bar Association's Science and Technology Section and the cofounder of Global Lawyers and Physicians, an organization dedicated to promoting health and human rights. He is an expert on health law and bioethics, author or editor of a dozen books, including *The Rights of Patients,* and writes a regular feature on "Legal Issues in Medicine" for the *New England Journal of Medicine.* He is a member of the Institute of Medicine and a fellow of the American Association for the Advancement of Science.

WILLIAM J BAIR, Ph.D., is retired from the Pacific Northwest National Laboratory, operated by Battelle Memorial Institute, where he held the position of Manager of the Life Sciences Center. His employment at the Hanford, Washington site was from 1954 to 1993. He holds a Ph.D. in Radiation Biology from the University of Rochester. His research was focused on the health effects of radionuclides, particularly with respect to deposition in the respiratory tract, with emphasis on plutonium and other transuranic elements. He has served on or chaired numerous Atomic Energy Commission and Department of Energy committees concerned with potential plutonium-caused health effects. He was a member of a National Academy of Sciences committee on "Hot Particles" and was vice chairman of the committee on Biological Effects of Ionizing Radiation, Alpha Radiation (BIER IV). He served on Committee 2 on Derived Limits of the International Commission on Radiological Protection (ICRP) and was a member of the National Council on Radiation Protection and Measurements (NCRP) for over 20 years. He was elected an honorary member of the NCRP. He currently is a member of the Science Advisory Board and Radiation Advisory Committee of the Environmental Protection Agency. He is a recipient of the E.O. Lawrence Award from the Atomic Energy Commission, the Distinguished Scientific Achievement Award of the Health Physics Society, Distinguished Achievement Citation from Ohio Wesleyan University, and was the NCRP Lauriston Taylor Lecturer in 1997. He is a fellow of the AAAS and the Health Physics Society.

RUTH R. FADEN, Ph.D., M.P.H., is the Philip Franklin Wagley Professor of Biomedical Ethics and Director of the Bioethics Institute, The Johns Hopkins University. She is also a Senior Research Scholar at the Kennedy Institute of Ethics, Georgetown University. Dr. Faden is the author and editor of numerous books and articles on biomedical ethics and health policy including "A History and Theory of Informed Consent" (with Tom L. Beauchamp); "AIDS, Women

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and the Next Generation" (Ruth Faden, Gail Geller, and Madison Powers, eds.); and "HIV, AIDS and Childbearing: Public Policy, Private Lives" (Ruth Faden and Nancy Kass, eds.). Dr. Faden is a member of the Institute of Medicine and a Fellow of the Hastings Center and the American Psychological Association. She serves frequently on national advisory committees and commissions. Most recently, she was the chair of the President's Advisory Committee on Human Radiation Experiments. Dr. Faden holds a B.A. from the University of Pennsylvania, an M.A. in General Studies in Humanities from the University of Chicago, and a M.P.H. and Ph.D. (Program in Attitudes and Behavior) from the University of California, Berkeley.

SHIRLEY A. FRY, M.B., B.Ch., B.A.O., M.P.H., Senior Advisor, Oak Ridge Associated Universities, is a physician specializing in radiation and occupational epidemiology. Her experience and interests also include the medical aspects of radiation accidents and the acute health effects of radiation. As Scientific Director of the Washington-based International Consortium for Research on the Health Effects of Radiation, she currently directs epidemiologic studies being conducted by collaborative research teams at institutions in the United States, republics of the former Soviet Union, and Israel. Committee service includes the Health Effects Group of the US-USSR Joint Coordinating Council on Nuclear Reactor Safety, the Senior Technical Review Group of the Amarillo National Resource Center for Plutonium, and the Uranium Task Group of the National Council for Radiation Protection and Measurements. Dr. Fry chairs the Oak Ridge Associated Universities/Oak Ridge National Laboratory's Institutional Review Board and is a member of several professional societies including the Radiation Research and Health Physics Societies, and the American College of Occupational and Environmental Medicine.

LAWRENCE O. GOSTIN, J.D., L.L.D. (Hon.), is Professor of Law at Georgetown University Law Center, Professor of Law and Public Health at the Johns Hopkins University School of Hygiene and Public Health, and the Co-Director of the Johns Hopkins/Georgetown University Program on Law and Public Health. Professor Gostin is also a Fellow of the Kennedy Institute of Ethics of Georgetown University and a member of the Steering and Executive Committees of the Georgetown University Institute for Health Care Research and Policy. Professor Gostin is the Editor of the "Health Law and Ethics" section of the *Journal of the American Medical Association.*

RAYMOND H. JOHNSON, JR., M.S., CHP, is a Certified Health Physicist and Licensed Professional Engineer. He is the President of Communication Sciences Institute, Inc. and the Director of CSI-Radiation Safety Training since 1985. He has managed a contract for radiation safety services at the National Institutes of Health since 1988. He has served as President of Key Technology, Inc., a radon measurement company since 1990. From 1986 to 1988 he served as

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Laboratory Director for radiochemical analyses with the Radiation Service Organization. He retired as a Commissioned Officer (0-6) with the U.S. Public Health Service in 1985 with 28 years of service. From 1970 to 1985 he was assigned to the U.S. Environmental Protection Agency where he served as Chief of the Radiation Surveillance Branch in the Office of Radiation Programs. He has a B.S. in Civil Engineering from the University of Vermont and Master's and Professional Engineer's degrees from the Massachusetts Institute of Technology and Harvard University. He conducted Ph.D. studies in radiochemistry at Rensselaer Polytechnic Institute from 1966 to 1972. He is currently President-elect of the Health Physics Society. He has served six years on the HPS Executive Committee and Board of Directors as Secretary and Treasurer. He is also President of the American Association of Radon Scientists and Technologists and President of the National Radon Safety Board. He is also a member of the American Nuclear Society, the Society for Risk Analysis, the American Industrial Hygiene Association, the Conference of Radiation Control Program Directors, and the Association for Psychological Type.

LEONARD D. MILLER is a retired U.S. Army Brigadier General. His background includes command of nuclear-capable field artillery units from battery to corps artillery level and command of Field Command, Defense Nuclear Agency (now Defense Special Weapons Agency) (1992-1993). Knowledgeable areas include command, control, communications, and Army organizations and operations.

WILLIAM A. MILLS, Ph.D., is self-employed, providing consulting services in radiation safety with emphasis on science, policy, and regulations. His prior radiation safety experience of more than forty years includes senior positions in the U.S. Public Health Service, the U.S. Environmental Protection Agency, the U.S. Nuclear Regulatory Commission, and the Oak Ridge Institute for Science and Education. Dr. Mills is a Fellow and Past President of the Health Physics Society, an Executive Council member of the International Radiation Protection Association, and a former member of the National Council on Radiation Protection and Measurements.

BERNHARD T. MITTEMEYER, M.D., currently serves as professor of surgery (urology) at the Texas Tech University Health Sciences Center where he also served as Executive Vice President and Provost from November 1986 to October 1996, during which time he also served concomitantly as Dean of the Medical School for three years. From March of 1985 to October of 1986, Dr. Mittemeyer was the Senior Vice President and Medical Director for Whittaker Health Services, a managed health care organization and subsidiary company of Whittaker Corporation in Los Angeles, CA. Prior to March 1985, Dr. Mittemeyer served as an officer in the U.S. Army Medical Department for 28 years, rising to the rank of Lieutenant General and Surgeon General of the U.S. Army.

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In addition to the above, other key military assignments included: Commander, Walter Reed Army Medical Center, Chief of the Medical Corps and Director of Professional Services, Commander of the 121 Evacuation Hospital in Korea and U.S. Forces Korea Surgeon, Chairman of Surgery and prior to that Chief of the Urology Division at Walter Reed Army Medical Center, and Medical Battalion Commander and Division Surgeon of the 101st Airborne Division in Vietnam.

THEODORE L. PHILLIPS, M.D., is Wun-kon Fu Distinguished Professor in the Department of Radiation Oncology and Associate Director of the Cancer Center at the University of California, San Francisco. He is past president of the Radiation Research Society and the American Society for Therapeutic Radiology and Oncology. Dr. Phillips is a member of the Institute of Medicine and recently served on its committee reviewing the NRC Medical Use Programs. He is a member of the Radiation Effects Research Foundation Scientific Council, which evaluates late effects of the atomic bomb exposures in Japan. His research has focused on late effects of radiation on tissues and on the treatment of brain tumors. He served on active duty at the U.S. Naval Radiological Defense Laboratory between 1963 and 1965.

GENEVIEVE S. ROESSLER, Ph.D., is associate professor emeritus, Nuclear and Radiological Sciences, University of Florida. She currently lives in Minnesota and is the editor-in-chief of the Health Physics Society's newsletter and the Society for Risk Analysis newsletter. Her areas of expertise include radiological risk, radiation biology, nuclear medicine, and health physics. She is a member of the National Council on Radiation Protection and Measurements; the Environmental Protection Agency Science Advisory Board; and the Amarillo National Resource Center for Plutonium, Senior Technical Review Group. Dr. Roessler served on the Technical Steering Panel of the Hanford Environmental Dose Reconstruction Project for eight years and teaches radiological risk courses for the Department of Energy. She is a Past President and a Fellow of the Health Physics Society. She received the Society's Founders Award and is a former editor-in-chief of the journal *Health Physics.*

RAYMOND L. SPHAR, M.D., M.P.H., a retired Navy physician, has served as Director, Undersea and Radiation Medicine in the Navy Surgeon General's office and as chair of the Navy's Radiation Effects Advisory Board. He was director of two Navy medical research laboratories engaged in operational, behavioral and epidemiological research and, subsequently, was chief of research for the Department of Veterans Affairs. He is a fellow of the College of Physicians of Philadelphia.

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STAFF

SUSAN THAUL, Ph.D., assumed the role of study director for the second year of the BREC project, having worked on both the BREC interim report and the mortality studies of participants at U.S. nuclear tests. Dr. Thaul had previously led IOM projects on women's health, national statistics, and health services research, among others. She received a Ph.D. in epidemiology from Columbia University and an M.S. in health policy and management from Harvard University. Heading the health staff of the U.S. Senate Committee on Veterans' Affairs (then chaired by Sen. Cranston), Dr. Thaul developed legislation in preventive health care and research, women's health care, sexual assault services and prevention, nurse and physician pay, and health effects of environmental hazards during service. Earlier positions were with the Agency for Health Care Policy and Research; the Harlem Hospital Prevention of Prematurity Project; and the NYC Health and Hospitals Corporation, where she held successive positions leading to Associate Director of the NYC Emergency Medical Service.

J. CHRISTOPHER JOHNSON, Ph.D., CHP, developed this study and was its initial study director. A health physicist, after retiring from the U.S. Army at the rank of Lt. Colonel, Dr. Johnson joined the staff of the Medical Follow-up Agency to pursue studies involving veterans who had participated in atomic weapons tests. He directed the epidemiological study of Operation CROSSROADS and served as study director for a substantial period of an ongoing study of five other nuclear test series. In the Army, he was chief of medical physics for the Army Materiel Command, Office of the Surgeon. Dr. Johnson received a B.S. in physics from the Worcester Polytechnic Institute, an M.S. in electrical engineering (biomedical option) from Kansas State, and his Ph.D. in nuclear engineering (medical physics option) from the University of Missouri-Columbia. He also holds CHP certification from the American Board of Health Physics.

HEATHER O'MAONAIGH began working as a research assistant for the Medical Follow-up Agency in June 1998. She is currently working toward her master's degree in demography at Georgetown University, having earned a B.S. in sociology from Western Washington University.

STEVEN L. SIMON, Ph.D., is a senior staff officer with the Board on Radiation Effects Research. He received his bachelor and master's degrees in physics from the University of Texas and his doctorate from Colorado State University in radiological health sciences. His specialties are measurement of ionizing radiation, in particular, in-situ gamma spectrometry and dosimetry/ dose reconstruction. His present interests pertain mainly to evaluation of environmental contamination and related exposures (past and present), and radiation-related health effects. He previously held positions as medical dosimetrist for pion radiotherapy at Los Alamos, assistant professor at the University of North Carolina

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at Chapel Hill and director of the Marshall Islands Nationwide Radiological Study from 1990 through 1995. He has conducted dosimetry evaluations in support of radioepidemiologic studies of thyroid disease and leukemia in Utah and directed a large thyroid-disease study in the Marshall Islands. He has participated in a variety of radiologic monitoring and assessments related to nuclear testing at sites worldwide including the Nevada Test Site, Marshall Islands, Mururoa-French Polynesia, and Semipalatinsk, Khazakstan. Presently, he is an adjunct faculty member at Colorado State University and associate editor of *Health Physics* and a member of the Health Physics Society, Society of Risk Analysis, Sigma Xi, and the International Union of Radioecologists. He has been with the National Academy of Sciences since 1997.

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