Chapter 10

RADIOLOGICAL CONSIDERATIONS IN MEDICAL OPERATIONS

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INTRODUCTION

The success of medical support operations in a nuclear war will depend to a great extent on the adequacy of planning, training, and preparation before hostilities occur. Nuclear warfare will produce a huge disparity between the number of patients requiring treatment and the available medical resources. This problem will be further complicated by the disruption of lines of communication; the isolation of medical units; and shortages of transportation, supplies, and equipment.

Preparation problems facing medical planners and commanders can be divided into two distinct categories: *(a)* staff-level planning, including actions that must be taken before the start of a nuclear war to minimize the prompt effects of enemy nuclear attacks, and *(b)* unit preparations to minimize the immediate and delayed effects of nuclear attacks, in order to ensure continued effective medical operations in a nuclear environment.

In many instances, the experience gained during conventional wars and peacetime nuclear incidents will be applicable to the casualties of a nuclear battlefield. A rigorous training and implementation program must be instituted at all levels of medical service for professional and nonprofessional medical personnel. Emphasis must be placed on practical, problem-related training rather than on theoretical principles.

The information in this chapter on tactical operations is extracted from current NATO doctrine for medical operations in a tactical nuclear environment.[1] The information on peacetime operations is from current Department of Defense doctrine from the Defense Nuclear Agency[2] and the U.S. Army.[3]

RADIATION INTERACTION AND DETECTION

The ability to recognize the potential for radiological damage is based on a knowledge of the basic interactions of radiation particles with biological molecules, and on the ability to detect the presence of radiation or radioactive materials. The need to measure or quantify a substance that dramatically affects the human system but cannot be detected with the senses has led to the development of radiation detectors and dosimeters based on the physical principles of radiation interactions. An understanding of the nature of radiation hazards and the characteristics of various radiation types will help in the selection of a specific radiation detector for a given situation.

Interaction

Radiation arises when excited or overly energetic atomic nuclei give off excess energy as their particles convert to a more stable arrangement. The excited atoms comprise the *radioactive material*—a physical substance that, when present in

sufficient quantity, can be weighed, measured, seen, or chemically separated. This radioactive material can be characterized by a *half-life,* the amount of time it takes, on average, for one-half of the excited material to convert (or decay) to stable, nonradioactive material. Depending on the material, the half-life can vary from less than seconds to many thousands of years. The shorter the half-life, the more probable it is that radiation will be emitted; the longer the half-life, the less likely are the atoms to decay. The amount of material present can be termed the *activity*, measured by the number of nuclear transformations per seconds (nts) or disintegrations per minute (dpm). The activity of a radioactive sample is a measure of its intensity. Units which measure activity are the *becquerel* (1 Bq equals one disintegration per second) and the *curie* (1 Ci equals 3.7×10^{10} disintegrations per second).

The excess energy carried away from the radioactive material comprises the radiation (Table 10-1). This energy may be carried away by particles of matter as they leave the nucleus (alpha, beta, or neutron radiation), or it may be emitted from the nucleus independently of any nuclear particles (gamma radiation). Either way, the radiation travels from the radioactive material until it interacts with the surrounding medium. The excess energy of the radiation rapidly dissipates through multiple successive interactions, until the particles recombine with the atoms in the medium. The amount of dissipated energy absorbed in the exposed medium is the *absorbed dose.* Units of absorbed dose are the gray (1 Gy equals 1 Joule/kg) and the rad (1 rad equals 100 ergs/g).

The interaction between radiations and any absorbing medium is *ionization.* In this process, the energy from the incoming radiation is transferred to an atom of the medium, exciting that atom and dislodging one of its orbital electrons. Each ionization event produces one ion pair, consisting of a free electron and the positively charged remainder of the atom. These free electrons, broken atomic bonds, and the resulting disrupted and distorted molecular arrangements are the basis of biological damage.

Gamma Radiation. Gamma radiation is a pure energy packet (called a *photon*), unaccompanied by any nuclear particle. Without mass or electric charge, the gamma rays have very little probability of interacting and will travel great distances through sparse media, such as air or biological tissues. This ability to penetrate and irradiate sensitive organs within the body makes gamma radiation hazardous. In order to increase the probability of interaction with and absorption of the radiation, gamma-ray shields are made of high-density concrete or lead.

Beta Radiation. Beta-particle radiation occurs when excess nuclear energy is emitted in conjunction with a high-speed nuclear electron. Because of its small mass and its one electric negative charge, the beta particle interacts more readily than does the uncharged gamma ray, traveling only several meters through air and penetrating only several layers of skin. The hazard from beta radiation is to the external skin surfaces; beta radiation cannot penetrate to internal organs unless it

is inhaled or ingested. Beta-particle radiation shields may consist of lightweight materials, such as a layer of clothing.

Alpha Radiation. The heaviest particle given off in nuclear decay is the alpha particle. It is 7,300 times heavier than the beta particle, and is positively charged with twice the beta particle's electric charge. Its mass and charge make the alpha particle a highly interactive form of radiation; it will travel only 5 cm in air and can be stopped by a sheet of paper. Alpha particles will not penetrate the external layer of dead skin and thus are no direct hazard as long as they remain outside the body. Alpha-particle-emitting materials are a hazard when they can be inhaled or ingested, and are then able to irradiate sensitive organs or tissues from within.

Neutron Radiation. Neutron particle radiation is emitted only during the instant of fission by the weapon material. A neutron particle has no electric charge but does have an intermediate nuclear mass (1,830 times the mass of the beta particle but only one-fourth that of the alpha particle). Like a gamma ray, the neutron can travel great distances through sparse media and can penetrate biological tissues. Unlike other radiations that interact with orbital electrons, neutrons are more likely to interact directly with the nuclei of atoms, particularly those having low atomic numbers. Thus, effective neutron shields are composed of materials with a high hydrogen content, such as water or paraffin.

Radiation Detection

No single instrument at present has all the characteristics necessary to detect all types of radiation. Accordingly, different types of instruments must be used, depending on the nature of the radiation hazard. For any type of instrument used, the time frame over which it operates can be instantaneous or continuous. A *rate-meter* indicates the instantaneous rate at which radiation is being detected, and an *integrating meter* gives a reading of the total radiation observed since the meter was turned on or restarted (zeroed).

Radiation-detecting instruments are based on the principles of the radiation interaction being observed. A detector that merely counts the incoming radiation particles is called a *radiation counter*. An instrument designed to collect and measure the number of ion pairs produced is termed an *exposure meter*; because the unit of exposure is the roentgen (R), it is also called an *R-meter.* An instrument that measures the total energy absorbed in a detecting medium is an *absorbed dose meter;* if the detector uses a tissue-equivalent absorbing medium, the detector is called a *rem-meter.* The characteristics of some of the more commonly used detectors are summarized below.

Ionization Chambers. Ionization chambers measure dose and dose rate from gamma and X radiations. A typical ionization chamber that measures total dose is the *pocket dosimeter*, which is the size of a large fountain pen (Figure 10-1). It has a chamber containing two electrodes, one of which is a quartz fiber loop that

is free to move on its mounting. Radiation entering the chamber causes ionization within the sensitive volume. The distance the fiber moves is proportional to the dose received in the chamber. Instruments of this type are sensitive to severe shock and humidity, but are small enough to be worn comfortably. The advantage of this instrument is that it can be read at any time (without the aid of a supplementary charger-reader) by simply holding it up to the light and looking into it.

Geiger-Mueller Counters. Geiger-Mueller counters are normally used for detecting single ionizing events that take place within the sensitive volume of the counter. The counters are rugged and sensitive to low levels of radiation. They are usually equipped with audible indicators of radiation detection that sound like clicks. Geiger-Mueller counters detect gamma photons or beta particles, but the detection of the former is less efficient. A discriminating shield is usually provided with Geiger-Mueller instruments; when it is opened, it admits both beta and gamma radiation. When the shield is closed, only gamma rays pass. Use of the shield may permit qualitative differentiation between the ionization caused by beta particles and that caused by gamma photons.

Proportional Counters. Proportional counters are used to detect one type of radiation in the presence of other types of radiation, or to obtain output signals greater than those obtainable with ionization chambers of equivalent size. Proportional counters may be used either to detect events or to measure absorbed energy (dose), because the output pulse is directly proportional to the energy released in the sensitive volume of the counter. Proportional counters are used for the detection of alpha particles, neutrons, and beta particles. They are often used in shielded laboratory facilities for sensitive low-level analysis.

Scintillation Counters. A scintillation counter combines a photomultiplier tube with a scintillating material, which may be a crystal or other phosphor (solid, liquid, or gas). Light pulses, produced in the scintillator by radiation, release electrons in the photomultiplier tube, and this tube then amplifies the electrons to pulses of current that can be counted. Various scintillation counters can detect alpha and beta particles, gamma rays, neutrons, protons, and electrons. The most common dosimeters for field use are alpha counters or gamma-ray detectors. Although energy dependent, scintillation counters are more efficient at detecting low-energy, low-level gamma-ray backgrounds than are Geiger-Mueller counters.

Thermoluminescent Dosimeters. A thermoluminescent dosimeter (TLD) responds to ionizing radiation by trapping excited electrons in metastable states within the detector's crystalline structures. When the TLD is heated, the electrons escape these traps, releasing light as they return to their lower energy state. The amount of light is proportional to the absorbed radiation dose. The TLD is an integrating dosimeter and requires an elaborate electronic readout device to interpret the absorbed-dose data. The readout instrument will zero the TLD so that it may be used again.

Radiophotoluminescent Dosimeters. Radiophotoluminescent (RPL) glass is a dosimeter material that will luminesce following an excitation pulse of ultraviolet light if it has been exposed to ionizing radiation. This effect is caused by radiation-induced changes in the crystalline electronic structure of the glass. As with TLDs, the response is proportional to the radiation dose. The RPL dosimeter sensitivity depends on the type and manufacturer, and ranges from 0.01 to several million cGy. This type of integrating dosimeter will not be zeroed by the readout device; it gives a total cumulative dose reading that fades very slowly with time.

STAFF-LEVEL MEDICAL PLANNING

As is the case with operations planning throughout the medical support system, the staff medical officer's planning is keyed to the functions of the forces supported by the medical unit. While the problems confronted by medical units on the nuclear battlefield will be similar in some respects to those associated with conventional warfare, there are some dramatic differences. These include the vastly increased numbers of casualties requiring care, the need to operate in fallout, and the requirements to treat and decontaminate combined-injury patients.

Handling Mass Casualties

Effective techniques of evacuation, medical management, and triage become increasingly important with very large numbers of patients. The problem of handling mass casualties is not limited to hospitals. It exists throughout the chain of medical evacuation, so the basic principles of triage must be understood by all medical personnel. Flexibility in applying these principles must be an established part of medical guidance and training.

Effects of Combined Injuries. Analyses of the expected battlefield situations in a tactical nuclear environment have concluded that a high proportion of the casualties will have combined injuries, most of which will be from thermal burns and radiation exposure. Burn injuries provide portals for infection, and both burns and radiation exposure decrease the casualty's immunity to infectious microorganisms. Medical planners at all levels must anticipate *(a)* personnel with low-level exposures from nuclear weapons, who may need immediate medical attention because of combined injuries, and *(b)* personnel with otherwise recoverable conventional injuries, but whose radiation exposures make their chances for survival poor.

Effects of Psychological Stress. It is possible to estimate the number of personnel who would be injured or killed by the thermal, blast, and radiation effects of a nuclear explosion, but it is much more difficult to predict the numbers and types of psychiatric casualties. The types of acute psychological problems that would occur would probably be similar to those in other combat situations, and the treatment methods developed during past wars would be appropriate.

The most important factor in preventing stress reactions is intensive training, which will result in less fear and prompter, more effective action. Because action relieves tension, the fear response is less likely to become severe or incapacitating. Preventing or treating stress reactions in nuclear warfare may determine the continuing effectiveness of a unit's combat performance.

Public Health Concerns. For centuries, the conduct and outcome of military operations have been profoundly affected by a small number of infectious diseases. Massive destruction from nuclear weapons could result in epidemics that would present serious problems for a military medical service, particularly when the effectiveness of civilian medical facilities and personnel has been diminished. In past wars, military medical forces have cared for civilian populations and have helped to rebuild nations ravaged by war. On the nuclear battlefield, the impact of classic diseases of disaster (such as dysentery, typhus, typhoid fever, cholera, and plague) may seriously affect the ability of the medical unit to treat battlefield casualties.

Logistical Support System. The success of medical support depends on the adequacy of prewar logistical preparation. Planning should provide not only for medical supplies and equipment, but also for general supplies, food, clothing, water purification apparatus, radiation-detecting and -measuring instruments, communications equipment, and modes of transportation.

The location of medical resources is crucial. Resources must be close to the area of probable greatest need, without being concentrated in areas likely to become targets for enemy attack. This means that medical planners must compromise between dispersal and the capability of the logistical system to move supplies and patients. Medical planners should take advantage of the stages of military preparedness that may precede the actual outbreak of hostilities. Because of the problems associated with long-term maintenance of medical equipment and medications in storage, extensive pre-positioning during peacetime is not practical.

Command Radiation Guidance. Line commanders at all levels will need advice from medical advisors about the effects of accumulated doses of radiation on the health of their personnel, as well as the hazards of potential exposures when operations must be conducted in areas contaminated with fallout. This advice must be practical and be based on an understanding of the requirements of the mission as well as on knowledge of the diverse human responses to radiation. The effects of radiation must not be either minimized or exaggerated, and the proper place of radiation effects relative to other hazards of combat must be understood.

NATO Standardization Agreement (STANAG) 2083 has established a Radiation Exposure Status (RES) category system (Table 10-2), incorporating the most recent guidance on the operational effects of radiation exposures.[4] This system will help military commanders maintain the fighting capability of the tactical forces despite the troops' exposure to ionizing radiation. When personnel have accum-

ulated sufficient exposure to be placed in a particular RES category, then commanders must restrict those units to activities in which additional radiation exposure is not expected, unless they are willing to accept the next higher risk to those units.

When exposures can be maintained below 150 cGy, the STANAG doctrine indicates that the overall effectiveness of combat units will not be significantly degraded. However, if the exposures become relatively large, tactical commanders must be advised of their forces' capability to continue operations. Generally, an effective military individual is one capable of carrying out assigned missions, some of which require a high degree of physical and mental effectiveness. Thus, in any attempt to relate radiation dose to this effectiveness, the complexity or physical demand of the task must be considered.

Combat-effective personnel will suffer from radiation sickness, but will be able to maintain at least 75% of their preexposure performance level. Performance-degraded personnel will be operating at 25%-75% of their preexposure performance. Combat-ineffective personnel will be capable of performing their tasks at 25% (at best) of their preexposure performance level.

Given an average dose of 400 cGy to a tactical unit required to perform a physically demanding task, the unit will become performance degraded about 2 hours after exposure and will remain so for longer than 1 month (Figure 10-2). However, if the required task is not physically demanding at that same radiation dose, performance degradation will occur at about 3 hours after exposure, and effective combat performance will recur 2 days to 2 weeks later, followed by a second performance degradation (Figure 10-3).

Of course, these predictions assume that exposure to ionizing radiation will be the combatants' only stress. The prediction of the performance capacity of irradiated persons will have to be considered with other stresses, such as conventional injury, endemic disease, continuous duty without sleep, and time in combat.

Radiological Concerns of Medical Personnel

When fallout occurs, insufficiently sheltered personnel will become contaminated. If these personnel are not wounded or sick, decontamination is not a medical responsibility; it will be done at the unit level under command supervision. If wounded personnel become contaminated, their hospitalization is more complicated. Fallout contamination can be hazardous to the patient and to attending medical personnel, although in contrast to contamination with chemical agents (in which the mere presence of the agent is life threatening), no immediate life threatening radiation hazard exists. Thus, the decontamination of patients and contamination-control procedures within the medical facility (although important) are lower priorities than the lifesaving treatment of conventional injuries.

Radiation Hazards in Patient Treatment. Radiologically contaminated patients are those who have been contaminated with fallout, which adheres loosely to clothing and skin in the form of dust, ashes, dirt, or mud. Once these residues have been removed, the patient does not present a radiation hazard. Patient decontamination should not precede or interfere with either lifesaving procedures or surgical preparation, but rather should be an integral part of these procedures. Furthermore, care must be taken to avoid accidentally forming a real hazard by accumulating contaminated waste in the decontamination area. Effective procedures for decontamination, followed by monitoring and properly disposing of contaminated waste, must be developed and used.

Three distinct hazards are associated with radiologically contaminated patients. These are the *whole-body gamma-radiation hazard*, the *beta-contact hazard*, and the *internal hazard* from inhalation and ingestion of contaminated material.

Whole-body gamma radiation is the most important hazard because gamma radiation has a long range in air. This danger should be considerably reduced by the time the patient reaches a medical facility, however, because the loosely adhering fallout residue will drop or brush off as the patient is moved. In addition, the initial decay of residual radiation associated with a nuclear detonation is very rapid. The whole-body gamma-radiation hazard to persons handling the patient will be several orders of magnitude less than that to the patient, because of distance and elapsed time.

The beta-contact hazard is a significant problem to the patient. If fallout residue remains on the skin for an extended time (several hours to days), beta burns may occur. These resemble first- and second-degree thermal burns. Because they affect only those skin surfaces directly in contact with the radiological contamination, gently brushing or washing the dust from the skin will eliminate the hazard to the patient. Wearing rubber gloves and surgical masks, as well as practicing good hygiene, will eliminate the hazard to medical personnel.

Under conditions of nuclear war, the minute quantities of radioactive material that might be ingested, inhaled, or absorbed through wounds are a relatively minor radiation hazard. Extensive decontamination therapy is unlikely to be used because of the large number of patients and the limited time, personnel, and available logistical resources.

Patient Decontamination. Patients can easily be decontaminated without interfering with required medical care. Simply removing the patient's outer clothing and shoes before admission will remove 90%-95% of the contamination. Once removed, contaminated clothing can be placed in bags, tagged, and taken to a remote section of the medical facility. The clothing can be decontaminated or disposed of by qualified personnel, as time permits.

The second phase of decontamination consists of washing or wiping the patient's face, hands, and any skin surfaces not previously covered by clothing. This should leave the patient 98% decontaminated, and can be done before or after admission.

The third phase of decontamination consists of either washing or clipping the hair and washing the scalp, and is required only if the patient arrives without headgear or if monitoring indicates that the hair is contaminated.

Unit Operations in Fallout

Whenever large areas are contaminated by fallout, the operations of all units will be hampered to varying degrees, depending on the level of contamination. When a serious radiation hazard exists, the medical unit commander will be faced with the question of whether to continue operations and accept hazardous exposures to unit personnel, or to take shelter—an action that may seriously reduce the unit's ability to care for patients. To make the correct decision, the commander requires the following capabilities:

- An effective radiation-monitoring capability to correctly measure the fallout radiation hazard
- The ability to make rapid estimates of anticipated dose and dose rates
- Satisfactory lines of communication with other units and headquarters to report the fallout situation and to receive fallout warnings, information, guidance, and orders

The commander will need to know:

- Whether the unit will be in a fallout area
- The expected time of fallout arrival (or how long before most of it will be on the ground and the dose rates will begin to decline)
- The maximum dose rates expected
- The adequacy of existing facilities as fallout shelters

Decisions about operations in fallout areas should be based on actual survey data. However, because it will be not be possible or desirable to expose monitoring personnel when dose rates are very high, a reliable method of estimating fallout decay is required (Table 10-3). Note that these calculations are accurate only after all fallout is on the ground and the dose rate is beginning to decrease.

By evaluating these data along with the operational situation, the commander will be better able to make the proper decisions about moving the unit, diverting

patients to other treatment units, moving into fallout shelters, or remaining in place and continuing normal operations.

Medical units that are required to remain in areas of high dose rates can survive and continue their patient-care activities if adequate shelter is available to shield against radiation. Many materials that are available on the battlefield will afford substantial shielding (Table 10-4), although some of them, such as concrete, require engineering support and prior construction. However, earth affords excellent protection and can be used with a minimum of engineering effort.

In some cases, construction will be unnecessary; terrain and structures that will afford excellent protection from radioactive fallout (such as tunnels, caves, culverts, overpasses, ditches, ravines, and heavily constructed buildings) may be available. In existing buildings, below-ground basements give the best protection. Windows and overhead floors can be sandbagged or covered with dirt to provide additional protection with a minimum of effort.

As a matter of policy, mobile medical units should locate in or near existing shelter. When this is impossible, adequate shelter must be constructed. These shelters need not be elaborate; they have to be continuously occupied only during the period of high radiation dose rates.

Three common field-expedient fallout shelters can be constructed quickly and without extraordinary engineering support.

Dozer Trench. For this type of shelter, a trench 2.7 meters wide and 1.2 meters deep is dug with a bulldozer. It is estimated that one bulldozer can cut six 30-meter trenches in about 5 hours. About 0.6 meters of trench would be required for each person to be sheltered; thus, in 5 hours, shelters can be constructed for about 300 people. Protection and comfort can be improved later by digging the trench deeper, undercutting the walls, and erecting tents over some portions of the trench. These trenches should provide adequate shelter for most fallout situations.

Dug-In Tents of a Mobile Hospital. The tents of a mobile hospital can be dug to a depth of 1.2 meters and would be more comfortable than the dozer trench. However, dug-in tents have two drawbacks: they offer far less radiation protection than dozer trenches, and they require considerably more engineering effort.

Vehicle-Earth Shelter. A very effective shelter can be constructed combining unit vehicles and dirt. Two large tents can be joined end-to-end. A shallow trench for the vehicles can be dug around them, with the dirt piled carefully on the outside of the trench. Another 15-cm trench should be dug for the outer wheels of the vehicles. This shelter can give as much as 80% protection if fallout contamination is removed from inside the rectangle thus created. Tent liners and ponchos can be used for this purpose. This shelter requires about 2 hours to build and can be

occupied or evacuated in minutes. As with other expedient shelters, it could be constructed when the medical unit occupies the position.

Regardless of the type of shelter used, a system must be developed for its efficient operation. In the case of medical units involved in the care of patients, it is usually advisable to separate the shelter management functions from those of patient care. Shelter management personnel must provide essential services, such as radiological monitoring; monitoring of water-storage facilities to prevent leaks and contamination; control of fire hazards; enforcement of health and sanitation rules; waste disposal; and provision of safe food, water, and sleeping facilities. Shelter management plans must be developed before the shelters are occupied, and the plans must be familiar to all assigned personnel.

MEDICAL RESPONSE IN PEACETIME RADIATION ACCIDENTS

A medical response to a peacetime radiation accident is similar, on a reduced scale, to the response of medical units on a tactical nuclear battlefield, although some of the radiological concerns differ. In a tactical nuclear environment (as in a large-scale nuclear reactor accident), gamma- and beta-emitting fission products become airborne fallout, exposing people to hazardous levels of external radiation. In a peacetime nuclear accident, the localized dispersal of alpha-emitting radioactive material is the governing concern. Alpha particles are not an external hazard, but when inhaled or ingested they can expose internal tissues to significant radiation doses. Due to the various levels of radiation and the different radioactive particles in tactical situations, the radiation-detecting equipment will be different from that used in peacetime.

Nuclear accidents may involve the military on short notice. Because the public will expect the response team to be knowledgeable, especially regarding medical care and public health, a review of past experiences and the current doctrine for handling nuclear accidents is essential.

Peacetime Constraints

In a peacetime nuclear accident, the medical unit is freed of some serious military concerns, such as hostile fire. Because nuclear weapons are designed so that a nuclear yield is virtually impossible without a complete sequence of deliberate actions, the major concern at a weapon-accident site is the dispersal of radioactive materials by either fire or the detonation of the conventional explosive. Thus, the consequences of a nuclear-weapon accident in peacetime are greatly reduced, and the medical response is concentrated on a few patients rather than directed toward mass casualties.

In peacetime, the concern about exposing personnel and the environment to radioactivity will have a much higher priority. Minute traces of material that would be inconsequential in wartime will assume great importance. Medical procedures must be performed to contain the contamination according to strict regulatory limits.

In managing a radiation incident, the response team will face pressure to provide details on the event. News media, public officials, and private citizens will demand information about the accident, casualties, critical aspects of the response effort, and its consequences. Medical-response personnel must be prepared to safeguard medical information in a manner that would be unnecessary during tactical operations.

Historical Perspective

The U.S. military services have experienced thirty-two accidents involving nuclear weapons through 1987.[5] The complexity of the accidents has ranged from *(a)* the simple dropping or dislocation of a weapon, resulting in physical damage but no bodily injury or dispersal of radioactive materials, to *(b)* the detonation of conventional explosives, spreading radioactive materials over hundreds of acres, contaminating private property, and requiring restoration efforts costing millions of dollars. The medical functions performed in these nuclear accidents illustrate the potential roles of military medical units that respond to future accidents.

Palomares. In January 1966, two U.S. aircraft (a KC-135 tanker and a B-52 bomber) attempted a mid-air refueling at 31,000 feet over the southeastern coast of Spain, but collided in the final stages of hookup. Wreckage of the two aircraft, including the four nuclear weapons aboard the B-52, rained down on the seaside farming village of Palomares, the nearby Spanish countryside, and the Mediterranean Sea. Four of the seven B-52 crew members survived the accident, but none of the four crew members of the KC-135 survived. Evacuation and treatment of the survivors were first provided by local Spanish authorities and hospitals. The first U.S. response personnel arrived at the remote site 12 hours after notification.[6]

Three of the fallen nuclear weapons came down on land; the fourth splashed down in the Mediterranean Sea and was not located for 81 days. The first weapon was found undamaged about 900 feet from the beach. The second was located the next day. It had suffered a partial high-explosive detonation, which made a crater about 20 feet wide and 6 feet deep. The third weapon was found an hour later, where it had landed within the limits of Palomares. It had also undergone high-explosive detonation, and nuclear material had spread up to 500 yards from the impact point. Luckily, no one on the ground was injured.

A contingent of American military and civilian personnel went to the Palomares area to work on recovery and the restoration of the accident site. The population rapidly increased to 747 (excluding offshore naval forces), which required

establishing an on-site medical support facility to provide emergency medical treatment, supervise on-site field sanitation, and assist workers who might be exposed to radiation. As the population increased, the responsibility for obtaining routine bioassay samples from those potentially exposed was given to the camp medical facility. No cases of hazardous radiation exposure occurred. Medical cases requiring treatment beyond emergency care were evacuated.

Within days after the accident, U.S. Air Force medical officers (specialists in aviation medicine) and enlisted personnel were at the site in a field dispensary. The initial task was to identify supplies of potable water. Most medical problems involved upper respiratory infections in personnel who were exposed to high winds and cool temperatures. Members of search parties who walked in the fields and hills suffered pulled muscles, cuts, scratches, blisters, and sprains. On-site medical support ceased when the base camp was closed in April 1966, after 84 days of searching, decontaminating, and restoring the remote site.

Thule. In January 1968, a B-52 aircraft on an airborne alert mission near Thule Air Force Base, Greenland, developed a fire. The pilot was unable to extinguish it and began an emergency descent to the airbase. Shortly after the descent began, the aircraft lost all electrical power, and the order to bail out was given and executed. The aircraft struck the sea ice several miles west of the base, and disintegrated from impact, explosion, and fire. Four nuclear weapons were on board the aircraft. Of the seven crew members who ejected, six survived. The seventh person died of a head injury, probably sustained when he ejected from the aircraft.[7]

Response forces sped to the scene, and a temporary camp was erected on the sea ice. Because the accident was close to the base, medical operations were mounted from the regular base facilities. Only camp sanitation was required in addition to normal medical services. As at Palomares, the medical clinic was responsible for collecting bioassay samples throughout the recovery period.

Because of the arctic location, the next sunrise occurred 24 days later. The darkness and severe cold affected recovery operations, requiring intense cold-weather training, frequent rest breaks, and time-consuming preventive maintenance.

Time was a crucial factor because the sea ice would melt in the approaching summer season, releasing the nuclear material into the environment. The aircraft and weapons had been almost totally destroyed, but fortunately most of the radioactive material had been immobilized when it froze into the snow and ice cover. Discoloration of the snow pack from the fire was an important clue in distinguishing contaminated from uncontaminated snow.

Innovation overcame some of the difficulties. The alpha detection instruments performed poorly in the severe cold. At first, batteries lasted only 10 minutes, and

the detectors were even more fragile than usual, so the operator wore the battery pack inside his parka to warm it with body heat. After site cleanup, the contaminated ice and snow were stored in old petroleum tanks and later transferred to specially modified containers for shipment to the United States.

Chernobyl. In 1986, an accident at the Chernobyl Nuclear Power Station in the Soviet Union initiated a sequence of events that mobilized civilian and military medical response forces worldwide.[8-11] Although the immediate fatalities and damage were localized, the extensive atmospheric fallout caused concern and action in health-care systems far from the accident site.

Following early reports of the accident, the U.S. European Command (EUCOM) established a Chernobyl Task Force to evaluate the accident's radiological effects on the health of American personnel in Europe. Directed by a medical corps officer, the task force was composed of representatives of public affairs and safety, and medical consultants in public health, preventive medicine, radiological hygiene, veterinary medicine/food sanitation, nuclear medicine, medical logistics, and medical operations.

The task force's initial mission was to provide medical screenings of U.S. military family members who were touring Leningrad and Kiev at the time of the reactor accident. The screening operations executed by army and air force medical units involved segregating planeloads of personnel, monitoring individuals and their baggage for external contamination, obtaining individual histories, performing thyroid counts and bioassay samples to assess internal contamination, and incorporating all analyses and interpretations into the individual's medical record.

At the request of the U.S. State Department, EUCOM deployed a radiation advisory medical team to assist the U.S. Ambassador in the USSR in defining and managing the immediate consequences of the accident. Composed of military health physicists, a physician, and a food service veterinarian, the team went to the U.S. missions in Leningrad and Moscow, evaluated the radiological environment, and advised the ambassador on potential hazards to the international community from the uncertain conditions.

Veterinary service personnel in EUCOM ensured the safety of local food supplies for consumption by American personnel. Food inspectors with radiation detectors traveled to wholesale markets, bulk issue points, and commissary distribution warehouses to monitor the supplies. Inspectors also obtained representative food and dairy-product samples for laboratory analysis. They determined that all foods met U.S. and host-nation contamination guidelines.

Although fallout data were available from State Department and host-nation authorities, the information was sometimes delayed or unavailable for some geographical areas in which Americans were stationed. The task force established an environmental monitoring program for U.S. communities, and obtained mea-

surements of external fallout exposure rates. Samples of air, soil, rainfall, and drinking water were collected from U.S. facilities throughout the command and analyzed by medical personnel, using preventive medicine units and medical treatment facilities.

Nuclear Accident and Incident Response and Assistance Organization

The Department of Defense (DOD) has established a policy for coordinating the response to a nuclear-weapon accident which *(a)* identifies the responsibilities for command at the scene, and *(b)* clarifies the coordination among DOD and other federal agencies, such as the Department of Energy (DOE) and the Federal Emergency Management Agency (FEMA).[2,3,12]

All U.S. Army installations with custody of nuclear weapons will have a dedicated response force that is prepared to respond to any nuclear incident. Initial response and service response procedures will be included in the standard operating procedures for the installation's Nuclear Accident and Incident Response and Assistance organization.

Initial Response Force. The Initial Response Force (IRF) is the nearest military installation, regardless of size, to respond to an accident, to take immediate emergency lifesaving measures, to provide security, to reduce exposures, and to provide a federal presence and humanitarian support. IRF members will coordinate on-scene hazard containment activities with civil authorities, and will remain in charge until arrival of the Service Response Force (SRF). The IRF unit should be trained and equipped to provide 24-hour capability.[3] The IRF commander will supervise all emergency forces and direct all operations at the scene, including, but not limited to, the following:

- Securing, safeguarding, and disposing of all classified material
- Treating casualties
- Determining actual and potential hazards
- Minimizing further hazards
- Requesting required assistance
- Providing control and logistical support of on-site personnel
- Handling claims, public information, and relations with local civilian groups
- Establishing communications between the accident site and higher headquarters

Service Response Force. The capabilities of the IRF are limited. Total control of the accident response will be the responsibility of the SRF, which should arrive within 24 hours after the accident occurs. The SRF will consist of an aggregate of personnel, with a military staff as the nucleus. Members of the IRF will be integrated into the SRF and will continue to play a major role in the response. The response force will be augmented by DOE scientific and technical advisers and by specialized teams from other services, as required. The SRF commander will be a general officer, designated as the On-Scene Commander (OSC).[2] Responsibilities of the OSC include, but are not limited to, the following:

- Safeguarding national-security materials and information
- Coordinating with federal, state, and local authorities (a liaison officer should be provided to local, state, or host-nation authorities and to the senior FEMA official by the OSC as soon as possible)[2]
- Ensuring that a public-health hazard assessment is made
- Notifying civil authorities of the precautions and other measures required for protecting public health and safety
- Establishing the priorities for response, recovery, and restoration efforts
- Coordinating, reviewing, and approving public information and news releases
- Communicating all required information and situation reports to the National Military Command Center and service operations center
- Coordinating with the senior FEMA official (in the continental United States) and state or host-nation authorities to restore the accident site
- Coordinating with the accident investigation board
- Obtaining assets required to support response operations

Guidelines for Medical Advisors

The Installation Medical Authority (for the IRF) and the Medical Staff Advisor (for the SRF) are responsible for planning the medical support required for their respective portions of the nuclear-accident response. They should maintain up-to-date plans and be prepared to train and supervise other medical personnel. Procedural guides should be prepared and distributed to any medical facility that may become involved in the support of such a response.

These medical advisors must be prepared to deal with the question of how much long-term radiation hazard exists for the local population in the contaminated

area. Another concern is the development of definitive treatment regimens for individual radiation casualties and combined-injury casualties. Several army, DOD, and DOE advisory teams will assist the medical advisors in determining appropriate medical guidance. Although these teams will respond to the accident site or treatment facility on request, prior coordination between the IRF and SRF medical advisors and the special teams is recommended.

Radiological Advisory Medical Team. The army has established the Radiological Advisory Medical Team (RAMT), which is staffed with health physicists, physicians, and technicians trained to evaluate radiological health hazards and manage radiation casualties.[13] At the accident scene and at the medical facility, the RAMT will assist with the following:

- Potential health hazards from radioactive contamination
- Medical treatment and decontamination of casualties
- Decontamination procedures for personnel, facilities, and equipment
- Control methods for radiation exposure during on-site recovery and restoration operations
- Medical surveillance or bioassay procedures during site-restoring operations

Medical Radiobiology Advisory Team. The Defense Nuclear Agency has established a Medical Radiobiology Advisory Team (MRAT) located at the Armed Forces Radiobiology Research Institute in Bethesda, Maryland.[2] This team is trained in the biomedical consequences of radiation exposure. It will help medical authorities to make definitive treatment decisions for individual casualties. The MRAT maintains treatment protocols that are relevant to the handling of radiation-accident injuries, based on state-of-the-art radiobiology research and human radiobiology data from previous accident victims.

Department of Energy Assistance. Major DOE installations have medical support capabilities that can be called on for assistance, if needed. Also, DOE facilities that routinely handle radioactive material are equipped to give medical treatment to radiological casualties. The Radiation Emergency Assistance Center Training Site (REAC/TS) in Oak Ridge, Tennessee, is prepared to deal with all types of radiation exposure and can provide expert advice and assistance.[2]

Rescue and Evacuation of Injured Persons at a Nuclear Accident Site

An accident involving a nuclear weapon will probably result in casualties. The injuries may be severe and numerous, like those from a serious multi-vehicle accident. Emergency personnel sent to an accident site must be well trained in trauma first aid. By the time medical personnel arrive at the scene, initial rescue

may have been effected and some first aid given. The medical personnel should assist in further rescue operations and begin evacuating casualties to the closest medical facility as soon as possible. They should notify the receiving facility of the nature of the accident and the number and type of patients involved.

The weapons materials give off short-range alpha radiation, which is not a hazard to attending personnel unless the actual radioactive material itself is inhaled. Standard military protective masks provide excellent protection. They should be worn by personnel inside ambulances until the patients are brought to the medical facility. Hospital personnel can safely wear a standard surgical mask.

After the patients have been brought to the hospital, the ambulance personnel and their vehicles should be decontaminated as soon as possible, even if monitoring facilities are not available. They must not be released until monitoring indicates that they are no longer contaminated. This requires special alpha-sensitive radiation equipment, which is generally not available at hospitals, and will have to be obtained from teams at the accident site.

The place for decontaminating ambulance personnel can be the same place used by other hospital personnel (such as the emergency room staff), preferably away from the emergency room. The place should have two entrances and a shower. A number of laundry bags should be set up and tagged. The personnel should strip off all clothing and put it into appropriate bags. If necessary, large tags should be attached to the clothing. Personal items, such as watches and jewelry, should be put into plastic bags. Protective masks should also be put into a special bag. A complete set of clean clothing should be available to personnel. If this is not possible, clean scrub suits should be provided until fresh clothing can be obtained. Complete monitoring is essential after showering.

Initial Care, Resuscitation, and Admission of Contaminated Patients

Every medical facility must have a plan for handling contaminated patients, while still restricting any changes in basic operations to those that are absolutely essential. The most important objective is to give injured patients proper, efficient, and rapid care without spreading the contamination. Traffic should be restricted, and a diagram of traffic changes should be posted in the emergency room area. If possible, contaminated patients should be treated in a room into which they can be brought without crossing main corridors in the building.

If the hospital has been warned of possible contamination, the route over which the patients are to be brought may be covered with paper. After the patients enter the treatment room, this paper should be carefully rolled up by personnel wearing caps, gowns, masks, and gloves. The paper then should be put into tagged bags. The process can be repeated as often as necessary. If patients are brought in over uncovered floors, the floors should be immediately covered with paper. The paper must be left in place until personnel with the proper monitoring equipment arrive

to help evaluate the hazard. Traffic over the paper must be limited to that which is absolutely essential.

Several laundry hampers should be available in the treatment rooms and adjacent hallways. They should be tagged so that all linens and clothing can be properly identified for later decontamination.

A treatment team should be organized to function like an operating-room team, and will require a moderate amount of prior training so that it will function smoothly and effectively. All members should wear caps, gowns, masks, and gloves. The physician and an assistant (if required) should be restricted to the area immediately around the patient. Circulating personnel in the room should bring supplies to the physician but should not touch the patient or the equipment. These personnel should not leave the room. There should be other circulating personnel who would bring supplies to the room but who should not enter the room.

The treatment priorities for a contaminated patient will vary with the seriousness and nature of the basic injuries. As lifesaving resuscitative measures are progressing, certain decontamination procedures can be performed without compromising the care of the patient. The patient's clothing should be removed carefully and put into a tagged bag for later decontamination or disposal. Valuables should be put into a tagged bag (preferably plastic) and held in a designated place for monitoring and decontamination; they should not be mixed with the valuables of other patients. The patients should be thoroughly washed, especially their exposed surfaces. The rinse water must be collected. Later disposal must be in accordance with the limitations of the laws of the nation in which the accident occurred. Consultation with expert personnel from among those at the accident site will be necessary to assure that this is done properly. Normal surgical management of wounds will be more than adequate for removal of radioactive contamination. Special debridement procedures are not required. Again, the rinse water or sponges should not be disposed of until expert advice has been obtained. Material objects from the wounds must be saved. If they can be separated from the rest of the waste, they should be put into marked bags. These fragments will be studied by experts and then disposed of through special procedures.

Patients should be admitted to designated wards or rooms and kept in semi-isolation to limit the spread of the contamination. All personnel should put on gowns, gloves, caps, masks, and shoe covers before entering the room and should remove them after each visit. All waste materials and linens must be marked and monitored. Frequent monitoring by trained health-physics personnel will be required to determine when it is proper to discontinue isolation techniques.

The patient's urine should be saved to be analyzed for radiological contamination. Normal urinalyses can be done safely on portions of the sample, but the laboratory should be notified that there is a potential hazard of contamination with

radioactive material. The laboratory must keep a record of the volumes of urine so that later calculations can be made of estimated body burdens of radioactive materials by appropriate laboratories. Fecal samples should also be taken and retained, in addition to nose blows and swabs, when directed.

Operating-Room Care of Contaminated Patients

Some of the patients from a nuclear accident may be injured severely enough to require extensive surgical care. These patients may be contaminated with any of a variety of radioactive and nonradioactive materials. Most of the materials will not be a significant hazard to operating-room personnel if simple precautions are taken. The basic organization and routine of the operating room should not be changed.

Since the hazard from any contaminating material will be respiratory, all personnel in the operating room should wear surgical masks at all times. Personnel with monitoring equipment will be able to advise the operating-room staff when it is safe to unmask.

Once an operating room has been used for the surgical care of nuclear-accident patients, decontamination and monitoring will be necessary before the room can be used for normal surgical cases. The surgical service must be prepared to lose the use of the room for the time needed for these procedures. In some cases, it may be practical for a hospital to set up a temporary operating room close to but not in the regular operating-room area. Alternative surgical areas may be used, such as a plastic surgery clinic or an outpatient surgical facility.

The actual surgery can be managed according to standard operating procedures for handling persons contaminated with infectious hazards, with the following additions or exceptions:

- All waste material must be saved in appropriate containers. Large plastic bags are the most suitable because they do not leak, if properly handled. The containers must be tagged so that they can be identified later and examined by qualified personnel.

- Used surgical gowns, caps, and gloves must also be considered contaminated. They must be removed carefully, and persons assisting in their removal must be wearing caps, gowns, and gloves. The masks should be put in a marked container.

- All personnel should shower completely after working on such cases and must not be released from the area until after they are monitored. This monitoring must be done by qualified technical-team personnel with special equipment.

SUMMARY

A nuclear event exposes people to a blast wave, thermal pulse, and ionizing radiation. If medical units are near the target area, injury and damage may disrupt their ability to perform. Thorough prior planning to adjust medical operations to the nuclear environment is essential. Intensive mission-oriented training that addresses the concerns of medical personnel can reduce their stress and lead to more prompt, effective action. The experience gained through medical operations in peacetime radiation incidents provides skills that are directly transferable to the medical support of the tactical nuclear battlefield. Unless medical personnel recognize and plan for the radiological effect on unit operations, the health-care delivery system may become a casualty of the nuclear event.

NUCLEAR WEAPONS ACCIDENT CHECKLISTS

Predeployment

Publications. Establish necessary publications, including the Nuclear Weapons Accident Response Procedures Manual (Defense Nuclear Agency Manual 5100.1) and pertinent service and local directives.

Medical Matériel. Establish necessary medical gear that can be immediately transferred to the accident site, ensuring that all shelf-life items are still effective. The gear will be based on the expected number of casualties and the amount of medical matériel that can be carried by the initial response team(s).

Directory. Establish a directory of local radiological resources, including their locations and telephone numbers. This should include military and civilian health-physics personnel and equipment, as well as the nearest whole-body counters and persons trained to use them. Also include the telephone numbers for REAC/TS as well as for local and state or regional coroners. Ensure that the lists include Auto-von, FTS, and commercial numbers, as appropriate.

Training Plans. Establish regular and routine training for medical personnel in the handling of radiological hazards from a nuclear accident. This may be a part of nuclear/biological/chemical training, but it should be emphasized that the hazards from a nuclear weapons accident differ from the hazards from most other radiation accidents. Ensure that medical team members from other units are also trained and aware of their roles.

Organization and Communications. Review the local organization chart for persons and groups to be notified in case of a nuclear weapons accident, and ensure that the lines of communication and the duties of medical organization are clear and thoroughly understood. Review the communications assets to be used in the field, and ensure that personnel are aware of proper operational procedures**.**

Transportation. Review the transportation assets to ensure that equipment and personnel can be quickly transported. Establish a priority list for personnel and equipment in case the accident site is difficult to reach. Establish contingency plans for movement by four-wheel-drive vehicles and by helicopter.

Field Deployment

Casualty Treatment and Triage. The first medical personnel to arrive on the scene should begin immediately to treat casualties. If casualties have already been treated, contact the treatment facilities (in conjunction with radiological controls personnel) to follow up on patient treatment and to perform radiological surveys of the facilities, as needed. Treatment should always be given in priority of medical condition. Radiation injury or contamination should not upset the normal triage pattern.

Mortuary Affairs. Make arrangements with local coroners or civil officials for the removal of fatalities from the accident site, if necessary. This should be co-ordinated with the legal and public affairs staffs.

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