CHAPTER 14

Health Physics

Even though nuclear ship design and regulatory safeguards be established, the constant presence of a radiation generator—the reactor—invokes a new state of vigilance by merchant mariners. There are those unending daily tasks of routine operation, maintenance, repair, cleanup, waste collection, and radiation sampling . . . all requiring perpetual attention to detect and remedy those unavoidable leaks, spills, and spreads of radiocontamination. Though far from death producing, these reactor plant housekeeping tasks do constitute potential health hazards to shipboard personnel. Inasmuch as nuclear radiation cannot be detected by body sensation, the use of personnel monitoring devices is required by all; special protective clothing by some; and quick wash-down and decontamination by a few. Keeping tab on all of these activities, day-to-day (hour-to-hour), comprises a new category of responsibility called "health physics." A good health physics organization is a prime asset in developing and maintaining the proper frame of mind toward nuclear duties aboard merchant ships.

14-1 Organization for Health Physics

The term "health physics" is a new concept to merchant shipboard, so a few words on its definition are in order.

"Health," here, means radiological health. That is, we are interested only in the biological effects (health harms) to operating personnel caused by nuclear radiation (alphas, betas, gammas, and neutrons). Non-radiation forms of health harm, illness, and injury do not come within the province of health physics.

"Physics," here, means nuclear physics . . . that is, the detection, identification, and control of radioactive species and radiocontaminants. The purpose of this detection and control is to prevent radiation hazards to personnel. Included in the physics aspects are the use, calibration, and maintenance of portable radiation instruments. This is a distinct function from the operational use of radiation monitors and reactor controls presented in Secs. 13-7 through 13-11.

"Health physics," therefore, is a hybrid of radiological health and nuclear physics pertaining to the protection of shipboard personnel. This suggests that health physics may not be a normal operating function of the deck or engine departments. Organizationally, health physics is a separate, independent responsibility in itself. On merchant shipboard, there might evolve a new departmental organization.

Table 14-1. Functions of a Nuclear Ship Health Physics Organization

Watch Routine Underway	Radiation Zone Control
· Periodic readings of radiation monitors · Test-check monitor alarms · Control of food and smoking · Check personnel dosimeters · Monitor personnel going off watch	· Establish safe entry procedures · Portable radiation surveys · Posting radiation levels · Test-check door interlocks · Periodic leakage inspection
Periodic Collection of Samples	Radiation Leaks and Spills
· Overboard sea discharges · Off-gas mast vent lines · Engineroom and auxiliary bilges · Containment air and dust · Passenger and cargo spaces	· Map and mark radiation area · Isolate or confine contamination · Establish safe cleanup procedures · Guard waste collections · Record incident in ship's log
Special Personnel Services	Decontamination Procedures
· Develop-record film badges · Charge-record pocket dosimeters · Advise on accumulated exposures · Fitting of protective clothing · Care of face and head masks	· Decision to "discard" or decontaminate · Separation of liquid-solid decontaminants · Acid wash or "paint-in" surface contamination · Control of decontamination laundry · Control of decontamination showers and sinks
Crew and Public Relations	Instrument Care and Calibration
· Health physics lectures to crew · Educational placards to passengers and crew · Posting of "permissible exposures" · Plug-up waste discharges in port · Provide port authorities with radiation records	· Repair of portable survey instruments · Calibration of portable instruments · Calibration of radiation monitors · Identity and correction of readout scales · Survey of instrument contamination

Table 14-1 lists some of the general functions of a health physics organization. Note that these are protective- and advisory-type functions only. If, for example, a high-level radiation leak develops in the primary shielding tank, the health physics organization would not be responsible for its containment, cleanup, and repair. This would be the responsibility of the engine department. However, the health physics organization would be responsible for *prescribing radiologically safe procedures* for performing the work, and would be responsible for the radiological records and reports in connection therewith. In this responsibility, members of the health physics organization would precede and accompany members of the engine department whenever performing radiologically hazardous duties.

To carry out its responsibilities, the health physics organization requires certain equipment and facilities. Some of the more important of these are listed in Table 14-2. The necessity for portable radiation detection and measuring instruments should be self-evident. So should the necessity for a calibration shop—equipped with radiation source standards and adequate shielding—to assure good instrument calibration at all times. To carry out responsibilities of radiation analysis, a separate radiation measuring laboratory is required.[*] Here, bench-type counters, scalers, and radioassay equipment would be provided to identify and measure the radiation samples collected. Of significance, also, is a special safe in which to lock up personnel radiation exposure records. This safe should be fireproof, portable, and sink-proof. We shall discuss later the administrative and legal importance of keeping radiation exposure records.

Table 14-2. Shipboard Facilities Required for Health Physics

- Radiation Instruments Locker
- Radiation Sampling Equipment
- Instrument Calibration Shop
- Radiation Standards Stowage
- Radiation Measurements Laboratory
- Personnel Records Safe
- Personnel Dosimetry Shop (with darkroom facilities)
- Protective Clothing Locker
- Decontamination Laundry
- Personnel Decontamination Equipment (showers, change rooms, etc.)
- Radiation Disposal Equipment
- Portable Gamma Shielding
- Decontamination Equipment Locker
    - vacuum cleaners
    - vacuum washers
    - vacuum blasters
    - ultrasonic devices
    - scrub brushes and buckets
    - wash down hose
    - sealed containers
    - warning signs
    - rope-off stands

In the case of the radiation monitoring equipment described in Secs. 13-7 and 13-8, the role of the health physics organization can be clarified. Fixed and semi-fixed monitoring equipment also are for the protection of personnel, it is true. However, such equipment is more a part of the operating plant than health physics equipment per se. Nevertheless, the health physics organization would be responsible for keeping the plant monitoring equipment in calibration . . . but not for its operational maintenance. This same principle holds true in other cross-over areas between the health physics and operating departments. For example, radiation-tight doors, radiation alarms, and radiation waste discharges would be periodically inspected by health physics personnel, but would be maintained by operating personnel.

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[*] Ref: "Radiation Safety for a Reactor," J. M. Smith, Jr., *Nucleonics,* June, 1953, pp. 41-45.

To properly delineate all health physics functions and facilities, a health physics manual is required. This manual—with its organizational details, listing of equipment, nuclear physics data, and tables of permissible exposures—would be tailored to each particular nuclear ship. Table 14-3 lists some of the essential contents of a health physics manual.

Table 14-3. Typical Contents of a Health Physics Manual

- Emergency Organization
- Principal Responsibilities
- Watch Responsibilities Underway
- Watch Responsibilities in Port
- Permissible Exposure Levels
- Location of Fixed Monitors
- Protective Clothing Equipment
- Instrument Calibration Procedures
- Instrument Repair Procedure
- Film Badge Routines
- Decontamination and Waste Disposal
- Radiation Report Forms
- Radiation Level Color Coding
- Exposure Time Charts
- Characteristics of Radioisotopes
- Health Physics Equipment List
- Radiation Units and Conversion Factors
- Potential Hazard Features of Reactor Plant

14-2 Qualifying Health Physics Personnel

There are no present ratings aboard merchant ships which are precedents for health physics work. Therefore, candidate health physics personnel could be recruited from any of the existing licensed ranks and certified ratings, subject to satisfactory completion of specialized training programs and qualifying examinations. Here is truly a *new opportunity* for merchant mariner personnel to acquire new knowledge and talents. If advantage is not taken of this opportunity, then health .physics personnel from shore-based nuclear plants and laboratories would have to be recruited.

As typical of the qualifications required, we would expect nuclear ship health physicists to be able to identify the type of radiation involved, and be able to discuss with operating personnel the realistic biological consequences if such radiation is unheeded. We would expect health physics personnel to be able to interpret the maximum permissible exposures in terms of the many situations which operating personnel must confront.

Of extreme importance is the mental attitude of health physics personnel. Neither must they be indifferent to radiation nor must they fear it. They must maintain a healthy, vigilant respect for it at all times. Actually, radiation is no more dangerous than any other hazard aboard ship—and there are many others—so long as safe practices are followed. Consequently, health physics personnel must be cooperative coaches to operating personnel, thus freeing these personnal of worry about radiation exposures.

We would certainly expect health physicists to be conversant with radiation dose units (mrem, μC, cpm) as here is one of the fundamental areas of radiation misunderstanding. Strictly speaking, a "dose" is the total quantity of radiation (of any type) absorbed by human tissue . . . in a single radiation experience. If it passes through the body, it does no harm; it must be absorbed. We speak of "dosage" as the sum of accumulated doses over a period of time. We speak of "dose rate" as the dose received per unit time. These three terms are related as follows:

$$\text{dose} = \text{dose rate} \times \text{time}$$
$$\text{dosage} = \text{summation of doses}$$

But no statement of radiation dose is complete without specifying the body location. If one finger absorbs 100 mrem, say, the effect is much less severe than if the whole body received 100 mrem. Though the same amount of radiation would be absorbed per gram of human tissue in both cases, the dosage (total radiation) absorbed would be quite different.

In addition to the above, Table 14-4 lists some of the subject matter with which shipboard health physics personnel would need to be familiar. How would they get this familiarity? By a combination of self-study, training lectures, and laboratory experimentation. At some future time, upon the attainment of a large fleet of nuclear merchant ships, formalized training manuals and programs undoubtedly would be arranged. In the meantime, however, health physics training would be by special arrangement with national nuclear laboratories and atomic energy contractors who have developed health physics training for shore-side personnel.

Upon completion of a recognized training program, health physics mariners would be qualified by examination in the same manner as other licensed and certificated personnel aboard merchant ships. At least one licensed health physicist would be required on each nuclear ship, and if the size of the ship warranted it, one or more certified health physicists would assist. A one officer and three men combination would permit one health physicist to be on watch at all times underway, performing duties appropriate to those functions listed in Table 14-1.

14-3 Biological Effects of Radiation

Except for rare radiation accidents, the probability of single-dose overexposure to nuclear ship personnel is extremely remote. The matter of more practical concern is the accumulation of small daily and weekly doses over a period of months and years. To predict the consequences of these dosages, if any, health physics personnel need to have a working knowledge of the biological effects of radiation.

Interestingly enough, nuclear radiation produces many effects which are characteristic of ordinary sunlight. A person exposed to sunlight, say, for four hours (the length of an engineroom watch underway) will experience sunburn. The burn will reach its peak a few hours after the exposure, then it will subside. The degree of the burn will be less severe for older persons than for younger ones; it will be less severe for darker persons than for lighter ones. For the same person, the burn will be less severe on the hands, feet, and face than on arms, legs, and body. These effects are directly comparable to the equivalent of "radiation burn."

Table 14-4. Typical Subject Matter for Training Health Physicists

Fundamental Physics
- Atomic structure
- Nuclear structure
- Nuclear transformations
- Nuclear fission
- Radioactivity defined
- Computation of half-life
- Fundamental particles
- Units of measurement
- Interactions with matter

Application of Physics
- Roentgen and its derivatives
- Permissible radiation exposure
- Permissible contamination concentration
- Permissible inhalation concentration
- Contamination and dust propagation
- Waste disposal concentrations

Radiation Detection Instruments
- The ionization mechanism
- Ionization chambers
- Geiger-Müller tubes
- Scaling circuits
- The proportional counter
- Scintillation counters

Radiation Detection Techniques
- Counting techniques
- Error and confidence intervals
- Pocket dosimeters
- Selection of survey instruments
- Survey instrument usage
- Detection with film
- Calibration techniques
- Instrument care and repair
- Photographic emulsion

Applied Health Physics
- Personnel monitoring procedures
- Personnel monitoring records
- Measurements of internal exposure
- Waste disposal practice
- Decontamination laundry
- Health physics public relations

Some Practical Problems
- Contamination control
- Special protective clothing
- Wear and care of masks
- Handling radioactive materials
- Use of portable shielding
- Decontamination procedures

Ref: "Lecture Notes; Health Physics Training Lectures", Sept., 1950, AECU-817, Oak Ridge National Laboratory.

There are many differences, of course, between radiation burns and sunburns. In the first place, instead of peaking a few hours after exposure, a radiation burn does not evidence itself until several weeks or months later. Secondly, the depth of radiation burn in human tissue is much greater than with sunburn. And thirdly, certain body parts are preciously radiosensitive. Radiation burns of blood-forming cells, gonads (reproductive organs), and lenses of the eyes have no counterpart in sunburn.

The most severe type of radiation burn likely to be encountered by nuclear ship personnel pertains to their hands. Human hands are the most used—and most abused—portion of the body. After a year or more of above permissible exposures, certain abnormalities of the skin and fingernails may become apparent. The skin may turn red and shiny. Some areas may become thick and leathery; other areas thin and devitalized. Cracks may become persistent; wartlike protuberances may appear here and there. There may be readily visible changes in the skin ridges of the fingers and striations of the nails. Generally, none of the changes to the hands would be discomforting, but they would persist long after exposure to the radiation. The real danger is that eventually cancer *may* develop in one of the abnormal skin areas. The manifestation of this may take as long as 25 years . . . even longer.*

Fortunately, one of the encouraging biological effects of radiation is the **recoverability of human tissues.** Providing the dosage is not too severe, complete recovery is possible upon cessation of the exposure to radiation. This is markedly true in the case of surface layers of the skin. Even the male gonads—of which there have been many conflicting statements about "sterility"—will recover.† This is not true, however, of brain cells and eye lenses. These parts do not recover; they do not repair themselves. This is why head and face masks are so important in high-level radiation situations.

To avoid the possibility of radiation overexposure, maximum permissible doses have been established. Health physics personnel must know their "dose tables" like their ABC's. These permissible doses are based on a whole body exposure of 300 mrem/wk categorized into age groups, skin, and the radiosensitive body parts (see Table 14-5).

Note particularly in Table 14-5 the doubling of the permissible dose for personnel over the age of 45. Conceivably, if all members of a nuclear ship crew were over 45 years of age, some cost savings could be realized. These savings would be in the form of less shielding, less sensitive radiation equipment, less radiation injury claims, etc. Here, for once, is a new technology favoring the employment of operating personnel of mature years!

14-4 Instruments for Radiation Surveys

Vigilance, in the health physics sense, implies the capability of surveying any radiation incident at any time . . . any place. To do this, portable (hand-carrying) instruments are required. These instruments must be capable of covering the whole gamut of radiation types, intensities, and species. A "radiation incident" involves leaks, spills, neutron-induced contamination, and circumstances beyond original safe designs and regulatory standards.

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* Ref: "Basic Concepts of Radiation Protection," C. F. Bonilla, *Nuclear Engineering*, McGraw-Hill, 1957, pp. 133-169.

† A direct quote from AECU-817 (Sept., 1950, p. 25) is as follows: "Sterilization in the male is produced by 800 to 1000 r in the testes. However, sterility in the male is reversible, and although there may be temporary sterility at lower levels, fertility is usually regained after a period of time." The permissible exposure of gonads is 300 mrem/wk. So, in order to produce temporary sterilization, a radiation dose 3000 times the permissible weekly dose would be required!

The feature of hand-carrying portability has been incorporated into literally thousands of shapes and sizes of radiation instruments. Some have pistol grips, brief case handles, strap handles; some are attached to short probes, long probes, and "fish poles"; some have earphones; some make audible clicks and buzzes; some light lights; some have multi-scaled meters. Some are shaped in the form of hearts, sausages, spindles, and shoe boxes. Many are known by nicknames such as "Betty Snoops," "Cutie Pie," "Samson," and "Poppy." For every conceivable shipboard radiation situation, a suitable portable instrument can be found.

Table 14-5. Maximum Permissible Radiation Doses: External Exposure

(m rem/wk)

Age	Whole Body	Head, Hands, Feet	Blood Forming Organs	Gonads	Lens of the Eye
under 45 yrs	600	1500	300	300	300
over 45 yrs	1200	1500	600	600	600

In general, all of these instruments can be grouped into the following five categories:

(1) Ionization Chambers
(2) Proportional Counters
(3) Geiger-Müller Tubes
(4) Scintillation Detectors
(5) Neutron Detectors

In each case, an "instrument" consists of a sensing element, electronic circuitry, and a readout device. The sensing element intercepts the radiation and produces a feeble electrical signal. This signal is amplified, shaped, and differentiated by the eletronic circuitry which, in turn, produces a readout signal proportional to the incident radiation. The readout device may be a meter, buzzer, or light.

The ionization chamber, proportional counter, and Geiger-Müller tubes are comparable in that they all operate on the ionization principle of a gas-filled tube (recall Sec. 12-7 and Fig. 12-4).* That is, radiation produces ions in the gas, and these ions are collected electrically. Operational differences between the three instruments depends on the applied voltage across the ion collection plates (see Fig. 14-1). In the low voltage regions, alpha radiations produce a distinctly greater number of ions than do beta radiations, hence the two curves in Fig. 14-1. At the higher voltage, the numbers of ions produced by alphas, betas, and gammas are indistinguishable due to what is termed "gas multiplication." Wide differences in capabilities between the three instruments are due to design features, sensitivity, and readout functions (see Table 14-6, page 308).

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* Typical gases used are air, argon, hydrogen, nitrogen, carbon dioxide.

The scintillation principle is entirely different from the ionization principle above. Scintillations are flashes of light. These flashes of light are produced when radiation passes through certain crystalline materials, notably: sodium iodide (NaI), lithium iodide (LiI), and zinc sulphide (ZnS). The flashes are about 10^{-8} sec duration. These flashes, in turn, become light rays which pass through a collimating material to strike a photocathode. From the photocathode material, electrons are produced . . . and collected electrically (see Fig. 14-2). Due to exceptional strides in recent scintillator development, scintillation detectors have become highly versatile.

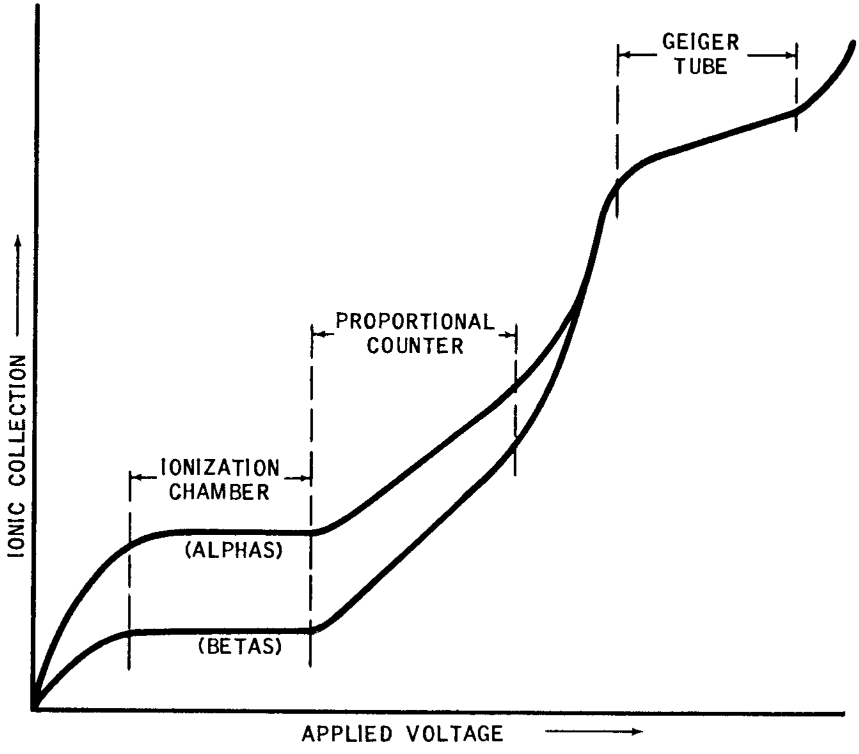

Fig. 14-1 Operational Regions of Gas-Filled Radiation Detectors

The principle of neutron detectors involves the use of neutron-sensitive coatings (recall Sec. 12-7). These coatings may be applied to ionization chambers or they may be mixed with scintillator materials. In either case, discrimination against gamma fields must be provided.

14-5 Identifying Radioactive Species

All of the foregoing instruments are used for radiation surveys. These surveys are the mapping and measuring of a radiation situation. The instruments tell the health physicist where, what, and how much radiation there is. But they don't identify the species of material from which the radioactivity comes. Different radiospecies promote different health harms and require different methods of cleanup and disposal. It is important, therefore, to identify them.

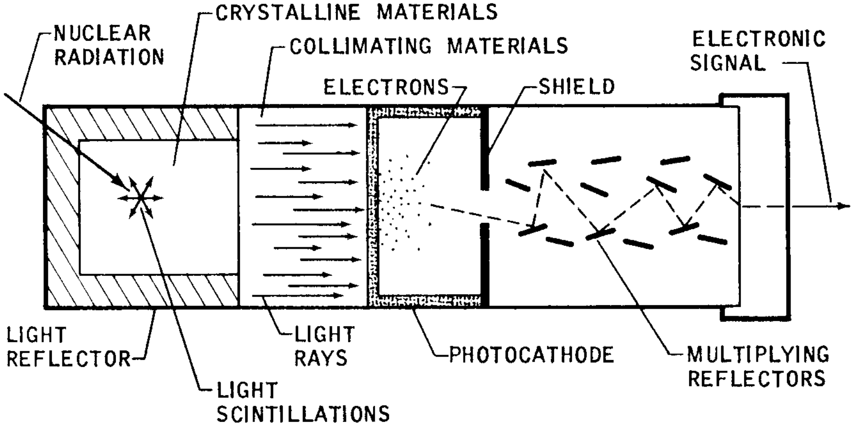

Fig. 14-2 Principle of the Scintillation Radiation Detector

The most characteristic feature of a radioactive species is its half-life. The half-life (as mentioned in Sec. 3-1) is the time required for the radioactivity to diminish (decay, disintegrate) by the factor one-half. The half-life is a unique constant of nature for each radiospecies. It will not vary with temperature, time, chemical state, nor any other change in the physical environment. The identity problem, therefore, is to determine the half-life from radiation samples and make comparisons with standard tables of known half-lives. The half-life determination is made with bench-type instruments in a laboratory.

Mathematically, half-life ($T_{½}$ is defined as

$$T_{½} = 0.693/\lambda \qquad \text{[Eq. 14-1]}$$

where λ (lambda) is the decay constant of the radiospecies (i.e., the fraction of radioactive atoms that disintegrates per unit time). From the basic laws of radioactive decay, we have

$$R = R_0e^{-\lambda t} \qquad \text{[Eq. 14-2]}$$

where R = number of radioactive atoms at time t, and R_0 = the number at time 0. Time t may be in any convenient units: sec, min, hr. Note that λ appears in both Eq. 14-1 and Eq. 14-2.

Samples of radioactive atoms R_0 are placed in shielded detectors, and the radioactive disintegrations are counted (see Fig. 14-3).[*] The readout

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[*] The main purpose of the shielding is to protect the sample against extraneous background radiation which otherwise would cause erroneous readings.

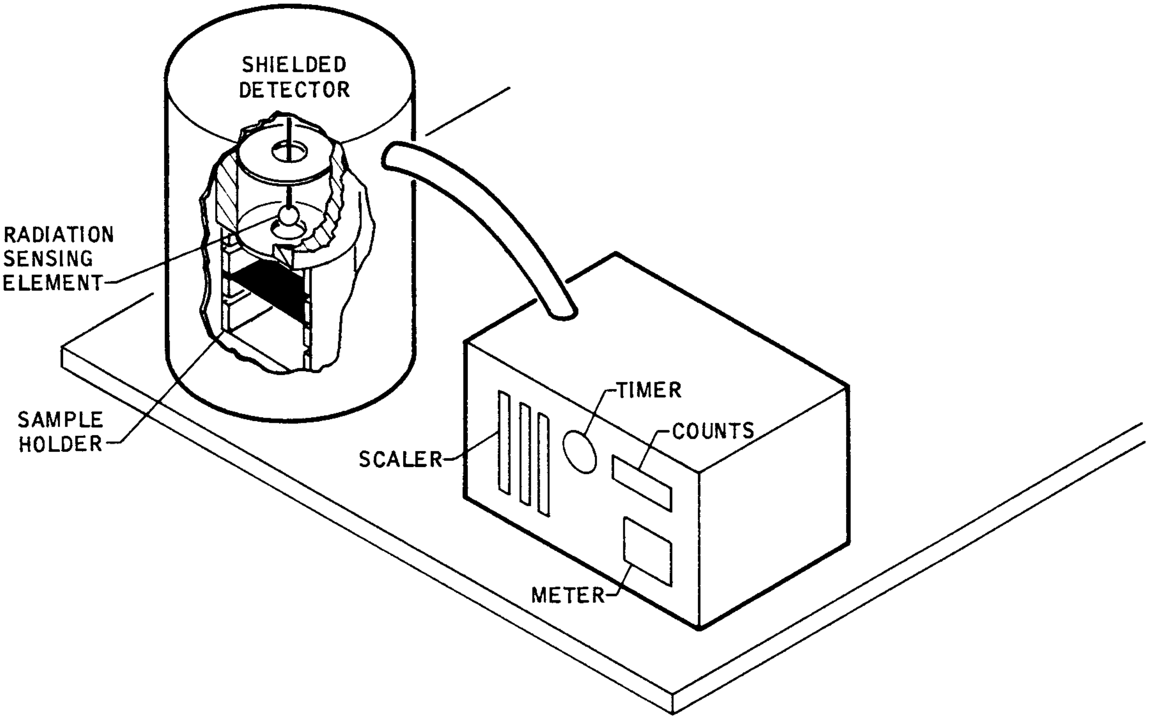

Fig. 14-3 Typical Bench Arrangement for "Counting" Radioactivity

circuitry of these detectors is proportionalized (scaled) to read directly the time rate of nuclear distintegrations. These readings are called "counts" per unit time. One instrument count (C) may represent 100, 1000, or any scaled number of the actual particles being radiated. This, then, gives us a convenient instrument relationship

$$C = C_o e^{-\lambda t} \qquad \text{[Eq. 14-3]}$$

Taking the logarithm of both sides of this equation, we get

$$\ln C = \ln C_o - \lambda t \qquad \text{[Eq. 14-4]}$$

The beauty of Eq. 14-4 is that on semi-log graph paper it plots as a *straight line* (see Fig. 14-4).

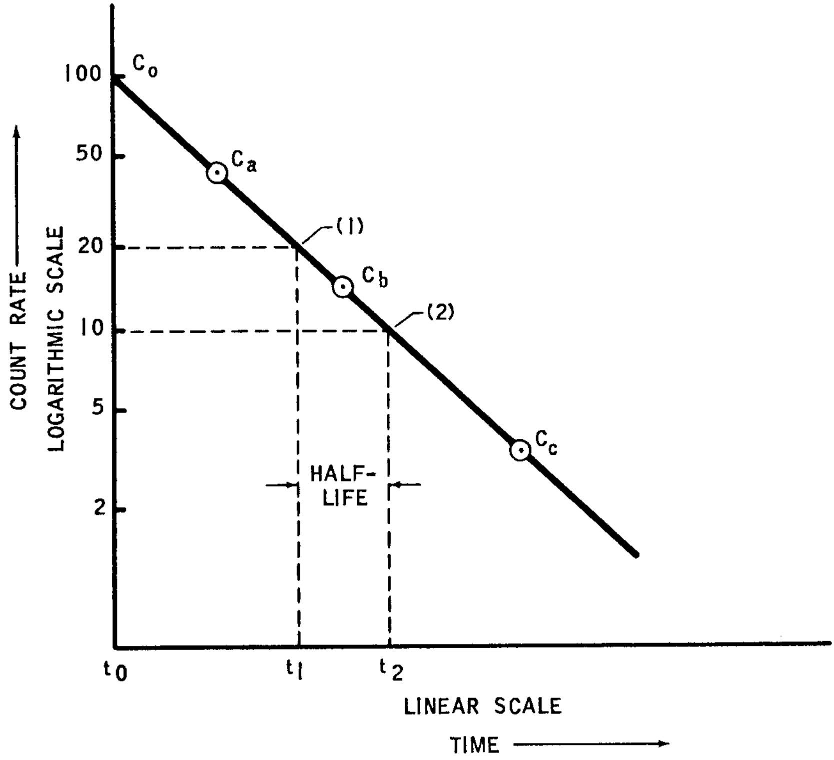

Fig. 14-4 Simple Half-Life Decay of Single Radioactive Species

The intercept on the vertical axis of Fig. 14-4 is C_o ($t = o$), and the points C_a, C_b, and C_c are plotted values of C at various times after $t = o$. The negative slope of the straight line is λ, but we don't need this. Starting at any point on the plot, say at (1), we read off C and note the corresponding time t_1. We come down the vertical axis to a value C/2 at (2) and read off t_2. The difference $t_2 - t_1$ is the half-life. We then compare this value with standard tables to identify the radiospecies. Or, we could measure the slope of the curve λ and compute $T_{1/2}$ from Eq. 14-1.

In other words, the health physicist takes a count-rate reading of his radioactive sample at any initial time t_0. At time t_a later, he takes another reading C_a; at time t_b, a reading C_b; and so on. From the plot of his readings, he can determine the half-life directly.

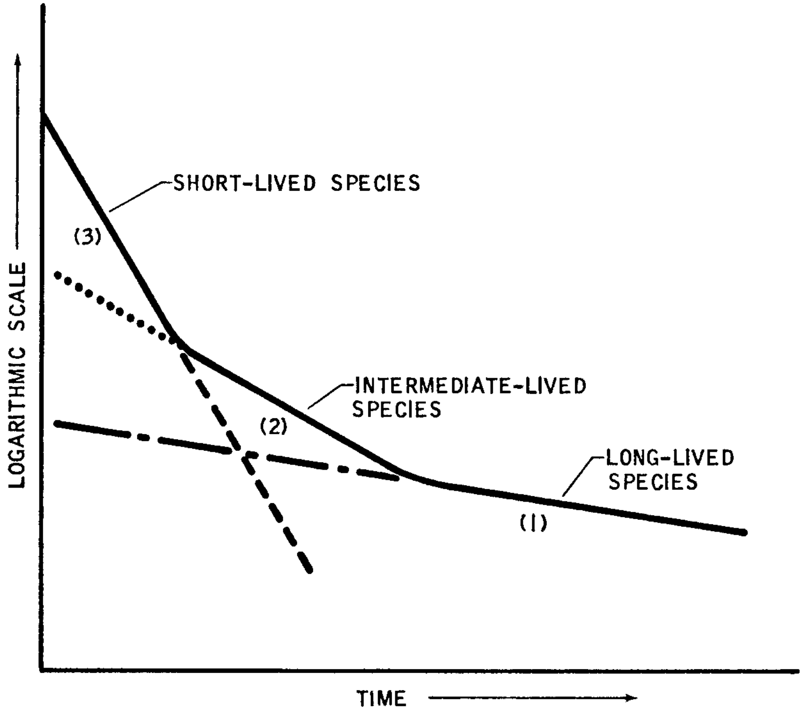

Fig. 14-5 Compound Half-Life Curve Typifying Three Radiospecies

The above procedure and Fig. 14-4 apply where there is only one radiospecies. But seldom is the identity problem this simple aboard ship. Usually, more than one radiospecies is involved, and distinguishing between them becomes more complicated.

In the case of two or more radiospecies, we get a curved line rather than one which is straight (Fig. 14-5). The problem is to make a series of straight lines out of the curve (starting from the right), and to determine the half-life for each straight-line segment. Each straight line represents one radiospecies. The longer half-lived species are those on the right (least slope) and, usually, those species are less harmful. The shorter half-lived substances (greatest slope) are the ones of principal concern because they send out more energetic nuclear particles. Consequently, considerable precision and care are required when analyzing the left portion of the radioactive decay curve.

14-6 Dosimeters Worn by Personnel

Radiation instruments which are miniaturized for continuous wearing by personnel are called "dosimeters" (dose meters). These little devices record the accumulated external dosage received, and are worn by all nuclear ship personnel, operating and health physics alike. Specific dosimeters are assigned to specific individuals on a periodic basis. At the end of a routine period, say once a week, the dosimeters are read and officially recorded in the health physics record of each mariner.

The principal types of personnel dosimeters are:

(1) Pocket Chambers
(2) Pocket Electroscopes
(3) Film Badges
(4) Film Rings
(5) Pocket Alarms

The pocket chamber and pocket electroscope are fountain-pen-size devices which clip into the shirt pocket. The film badge is I.D.-card size and clips onto outer clothing; the film ring fits onto the center finger of the most used hand. The pocket alarm, largest of all personnel dosimeters (approximately 1 x 2½ x 5 inches) slips into the coat or outer garment pocket, or clips onto the belt. It is used only when entering a known higher-than-permissible radiation zone. The alarm can be set to any predetermined dose whereupon a buzzer sounds as a warning to get out. Any of these personnel dosimeters can be designed to respond to beta-gamma or to neutron radiations.

The pocket chamber and electroscope are miniaturized variants of the ionization chamber discussed in Sec. 14-4 (and Table 14-6). In lieu of an active voltage supply, an electrostatic charge is stored across the ion collection electrodes. The charging is done by an external voltage source.* When radiation enters the charged area, the resulting ions discharge the dosimeter. Thus, pocket dosimeters have to be recharged periodically.

Table 14-7 lists the important differences between the two types of pocket dosimeters (see also Fig. 14-6). Because the electroscope is self-reading, it provides an important psychological advantage to the wearer. At any time, one can hold up his pocket electroscope to the light and read directly his mrem accumulated exposure. Because the electroscope is less rugged than the non-self-reading ion chamber, both types generally are worn.

Film badges and film rings use a photographic emulsion selectively sensitive to each type of radiation. The dosimetry features of the film are its tiny grains of silver bromide (AgBr). When radiation encounters these grains, the silver is deposited out resulting in a darkening of the film. The density of the darkening is a measure of the radiation received.

Usually, two or more film types are combined into a film badge (see Fig. 14-7) or into a film ring. These film dosimeters are extremely rugged

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* When a voltage V is connected across two electrodes, then removed, a charge $Q = C_iV$ is stored across them (C_i is the mutual capacitance).

and have a wide range of dosimetry: up to about 30,000 mrem. These features make film dosimeters particularly practical for shipboard use. However, film dosimeters require the use of dark-room facilities for development and densitometers (density meters) for reading the radiation received.

Table 14-6. Features of Radiation Instruments Using the Ionization Principle

The Basic Principle

Ionization is the removal of electrons from gas molecules (indirectly) by radiation, thus forming positive ions and free (negative) electrons. Depending on characteristics of the ionization field, the net flow of electrons to a collecting electrode will produce a detectable electric current.

Instrument	Typical Forms	Applied Voltage	Gas	Radiation Types	General Comments
Ionization Chamber	Closed cylindrical conducting chamber with central (axial) collecting electrode insulated from cylinder.	0-200	Dry air (atm. press.)	All types; particularly alphas	Can detect individual "pulses" produced by individual radiations; requires highly sensitive electrometer for readout.
Proportional Counter	Open chamber of conducting walls with collector ring electrode.	200-600	Flowing gas (multiplication to 10^5)	Alphas and betas; particularly betas	Requires less external electronic circuitry; good for low energy nuclear particles; good discrimination between betas and alphas.
Geiger-Müller Tube	Multi-shaped vacuum tubes with cathode (electron emitter) and fine wire collector.	800-1000	Argon, neon (multiplication to 10^9)	Betas and gammas; particularly gammas	Greatest sensitivity of all, but least efficiency; output signal independent of primary ionization initiating it; operation limited by gas saturation of tube.

The pocket alarm is a little ionization chamber with a hand-flashlight-battery power supply. Its only readout is a buzzing noise when the accumulated dose reaches a preset or predesigned limit.

14-7 Instrument Care and Calibration

We have discussed now three functional categories of health physics instrumentation. These instruments are categorized by relative physical size and types of power supply, as follows:

(1) Bench Counters—shop—ship's power supply
(2) Portable Detectors—hand-carried—battery power supply
(3) Personnel Dosimeters—worn—no power supply

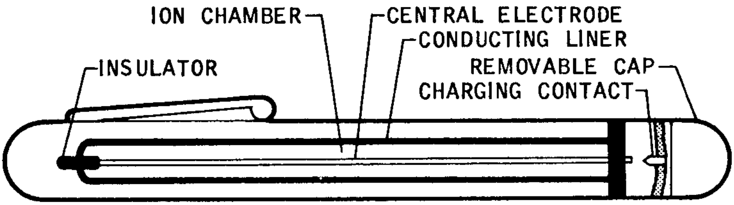
Because these instruments provide vital shipboard information, their care, maintenance, and calibration are a shipboard responsibility.

Table 14-8 lists some of the typical malfunctions experienced by the above instruments. Some of the causes of these malfunctions also are listed. To this list of causes, we have to add the shipboard environment, banging around, saline atmosphere, and tampering. For the most part, the corrections required are zeroing meters, replacing tubes, renewing batteries, checking electrical contacts, and general cleaning and tightening.

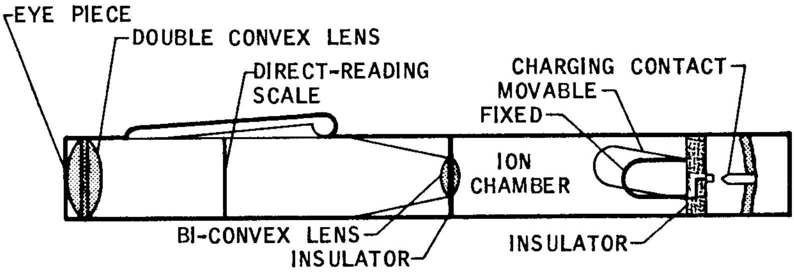
So it is not necessary that health physics personnel be electronics experts. If such personnel will follow the manufacturer's instructions for each type of instrument, all radiation instruments should give good service.

Table 14-7. Important Differences Between "Fountain Pen" Dosimeters

Pocket Instrument	Chamber Design	Range mrem	Self-Reading	Utility
Ion Chamber	Central Electrode Cylindrical Shell	0-300	No	Rugged
Electroscope	Fixed Fiber Movable Fiber	0-200	Yes	Fragile



POCKET CHAMBER



POCKET ELECTROSCOPE

Fig. 14-6 Two "Fountain Pen" Type Personnel Dosimeters

The mentioning of "manufacturer's instructions" requires some clarification. There are thousands of health physics instrument manufacturers and they all say their instruments are rugged, reliable, accurate, easy to maintain, etc. Maybe so. But the correction of malfunctions is not always self-evident to the nuclear ship health physicist working in a violent

North Atlantic sea or in balmy tropical waters, many thousands of miles from a "manufacturer's rep." This points to the necessity for some form of maintenance instruction standards for shipboard instruments. The instructions should be absolutely complete and in such format that they can be appended to the health physics manual.

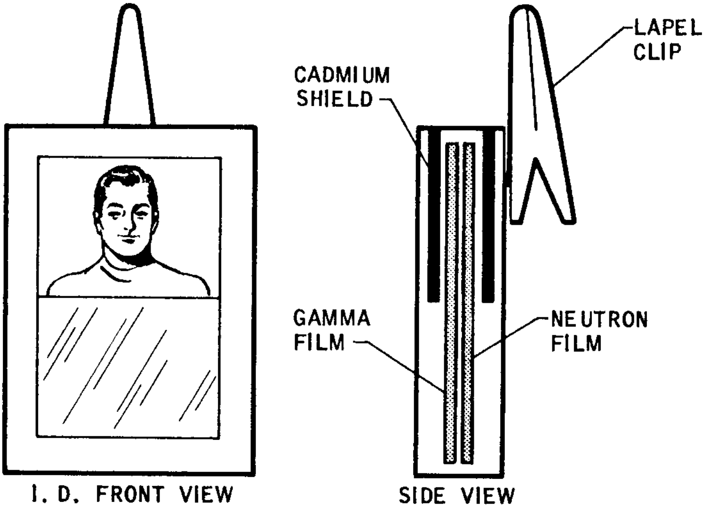


Fig. 14-7 Typical Features of a Personnel Film Badge

Instrument calibration sources are small radioactive samples of known species, of known radiation type, and of known activity rate.* These sources are in the form of small vials or buttons which range in source weight from 0.1 to 500 milligrams. Calibration sources are certified in terms of gamma or neutron radiation equivalent, and are housed in small shielded containers.

When using a calibration source, two precautions are required. One, screen out extraneous background radiation; two, use only clean, noncontaminated instruments. Otherwise, significant errors will be introduced. The instrument-recorded radioactivity of the calibration source is compared with the known radioactivity of the source, and the instrument error, plus or minus, is noted.† This may be done with a series of sources—of progressively higher radiation levels—to give representative check-points throughout the instrument range.

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[*] Typical calibration sources are radium, radium-beryllium, and cobalt-60.

[†] Remember, the calibration source itself is a radioactive species. It has a half-life and is subject to radioactive changes with time.

On shipboard, the calibration of health physics instruments would be a biweekly, but not greater than monthly, routine. A special calibration bench—with source holder, precision-marked distances, lead and wax brick shields, and detector holders—is useful for this purpose. An instrument that calibrates greater than 10% error (after meter adjustments, new tubes and batteries, etc.) should be set aside. Chances are the sensing chamber and/or the electronic circuit may be at fault. Correcting these design faults is beyond the scope of responsibility of health physics personnel.

Table 14-8. Typical Radiation Instrument Malfunctions and Their Causes

Some Malfunctions

- Meter needle fluctuates badly
- Meter reads above/below scale
- Will not zero on sensitivity scale
- Reading when no radiation present
- Reads less than known radiation
- Zero changes when instrument rotated
- High electronic noises and scratches
- Power on, but no meter or audible response
- Intermittent operation during handling
- No change with meter scale change
- Instrument unduly warm
- Difficulty with probe shields and handles

Some Causes

- Defective sensing elements
- Bad electronic tubes
- Batteries low or dead
- Corroded or dirty connections
- Ionization gas low or lost
- Neutron-sensitive coating broken off
- Loose electrical connections
- Contamination on instrument
- Burned out capacitors, resistors
- Leakage in high voltage circuit
- Meter in poor electrical balance
- Short-circuits and groundings

14-8 Procedures in Radiation Incidents

A radiation incident is one in which the radiation level exceeds normal permissible limits, but which is not of sufficient magnitude to be classed as an emergency or a disaster. Incidents are low-order radiation accidents caused by leaks and spills of various forms. The major consequences are contaminated surface, air, and liquid materials in the vicinity of the incident.

The principal difficulty in a radiation incident is the discovery of it. It may go unnoticed for days. If it does so, the spread of contamination may become profound. Here is a typical example.

A case is on record where a 40 mg radium calibration vial (about 1/10 the size of an aspirin pill) was unknowingly stepped on.* Before the incident was completely under control, the contamination had spread to 26 rooms and their associated halls, stairs, and furnishings. The accumulated radioactive wastes filled more than 200 drums (55-gal size)! Table 14-9 lists the radioactivity of everyday items touched or walked on—unknowingly—by the person who originally stepped on the vial. Should any comparable incident happen aboard a nuclear ship, the spread of contamination throughout watch stations, staterooms, decks, and dining areas would be quite disconcerting.

Table 14-9. Actual Spread of Radioactivity from 40 mg Radium Incident

Object	Radioactivity* (dpm/85 cm^2)
Door knob	1, 500
Towel	3, 000
Pillow	4, 000
Water faucet	125
Bed spread	1, 700
Carpet	2, 300
Armchair	2, 700
Writing desk	3, 000
Slippers	275
Chair seat	4, 000
Pencil	1, 500
Shoes	20, 000
Clothes brush	1, 500
Raincoat	4, 500

* Permissible radioactivity in this case was set at 300 dpm/85 cm^2 (dpm = disintegrations per minute)

Shipboard health physics procedures to avoid widespread contamination start with routine monitoring of all personnel going off watch from nuclear plant areas. These personnel must leave their watch stations via specified routes through hand-and-foot counters, clothing counters (called "friskers"), and other personnel monitoring devices. Any excess permissible readouts would involve questioning the person concerned in order to trace back to the origin of the contamination.

Health physics personnel would proceed to survey the incident area and mark it off against access. Samples would be taken—in microgram (millionths of a gram) amounts—to more accurately determine the nature and

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* Ref: "Hazard Evaluation and Control After a Spill of 40 mg of Radium," Skow, Vandivert, and Holden, *Nucleonics*, Aug., 1953, pp. 45-47.

extent of the radiocontamination involved. Sampling techniques would include smear samples (wiping filter paper across surfaces), micropipet samples (syringe-operated glass capillary tubes for liquids), and air samples (with hand vacuum pump and container). Sufficient samples would be taken to get representative data consistent to within ± 10%. From these samples, the actual radiation level would be determined in microcuries (μC) or disintegrations per minute (dpm) as appropriate.*

At this point we should clear up any misunderstanding between radiation levels in mrem (milliroentgen-equivalent-man), μC and dpm (discussed in Sec. 13-8). When we use the term mrem, we are implying the idea of distance from the radioactive source. We may not—and often do not—state what this distance is, but we imply it, nevertheless. When we use μC or dpm, we are implying the radioactivity at the source itself. We can convert μC to mrem by the footnote expression in Sec. 13-8.

Generally speaking, it is more convenient to use mrem for health hazards *external* to human beings (recall Table 14-5). People can lessen the hazard by moving greater distances away. The collateral implication is that the contaminating hazard is fixed or confined and will not move on its own accord toward human beings.

On the other hand it is more convenient to use μC or dpm for those contaminants which readily can be spread around, ingested, or inhaled. These contaminants constitute *internal* health hazards (recall Table 13-1) which, when once inside the body, cannot be lessened by distance or by moving around. Hence, generally, we use mrem for external health hazards and μC for internal health hazards. Generally, also, mrem implies larger permissible doses than μC.

Unless personnel are deliberately careless, surface contamination can be roped off and liquid contamination can be contained, so that neither presents an immediate hazard. The problem requiring immediate health physics concern is airborne contamination. This may take the form of radioactive dust, water vapor, mist, smoke, or fumes. These airborne radiocontaminants are all too readily circulated among personnel, equipment, reactor plant, and ship compartments. Consequently, the first precautionary step in a radiation incident is to control the area air either by shutting off the ventilation or by inserting additional filters in the exhaust ducts. If possible, the contaminated air should be diverted (carefully) overboard. Once the airborne contaminants are under control, decontamination procedures can begin.

14-9 Fundaments of Decontamination

If a contaminated area is under control, that is, confined, and if the extent of radiation is known, the first fundament of decontamination is to take time to **think out what to do.** Emergency-like procedures for nonemergencies are uncalled for. The situation has to be appraised intel-

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* Remember, instruments read cpm; to get dpm, the instrument scaling factor must be used.

ligently in the light of nuclear shipboard circumstances existing at the time. No standard decontamination procedure can be prescribed.

One of the first questions to be answered is: What degree of operational necessity is involved? That is, what period of time can be allowed before operational requirements necessitate use of the area or the equipment contaminated? Obviously, the longer the period of time available, the more adequate the formulation of decontamination plans. The preparation of these plans is largely the responsibility of health physics personnel.

Table 14-10. Partial Checklist of Considerations for Decontamination Plan

Prepare Decontamination Personnel

- Set exposure time limits
- Face masks and head gear
- Coveralls and gloves
- Shoe coverings, "step-off" mats
- Instructions and sequences
- Dry-run practices
- No smoking, no eating
- Reliefs and records

General Decontamination Procedures

- Draw off airborne contaminants
- Suck up dust, loose particulates
- Sweep up loose debris
- Sop up, wipe up wet surfaces
- Drain off liquid contaminants
- Wet-scrub solid surfaces
- Vacuum blast metal surfaces
- Disconnect items for glove box

Prepare Decontamination Equipment

- Vacuum cleaners and filters
- Scrub-down gear and pails
- Absorbing paper and tongs
- Vacuum wash-down gear
- Vacuum pumps and tanks
- Vacuum blasting equipment
- Special ultrasonic equipment
- Sealed containers for decontaminants

Personnel Decontamination Procedures

- Remove shoe coverings, gloves
- Remove head gear, coveralls
- Remove all other clothing
- Scrub thoroughly in shower
- Monitor body when dry
- Recheck finger nails, eyes, nose, ears
- Remonitor hands and feet when dressed
- Monitor used clothing; launder or dispose

Table 14-10 is a partial checklist of considerations that would be incorporated into a decontamination plan. The principal features of such a plan (second fundament) are to select and instruct decontamination personnel and provide them with adequate equipment to do their job. In this regard, except for minor incidents, the actual decontamination work would be done by ship's maintenance personnel. Before starting any decontamination work, the safe length of time for each person in the area must be established. Then, each person would set his pocket alarm accordingly.

The third fundament of decontamination is to clean up and remove *all loose contaminants*—including dust, liquids, and debris. These constitute internal health hazards and it is important, therefore, that they be cleaned up first.

The dust and airborne contaminants are sucked up through vacuum cleaners with special collection bags, filters, and exhaust hose. Wet contaminated surfaces and drippings are sopped up with disposable absorbing paper on special tongs, and placed in sealed collection pails. Contaminated liquids, say, in bilges or trapped in deck pockets, machinery foundations, and other structural irregularities, are vacuum pumped into transportable sealed containers. Loose surface contaminants are wet scrubbed and picked up by the foregoing means. All contaminated waste collections are allocated to the ship's regular waste disposal system (Sec. 12-11).

A fourth fundament of decontamination is to decide what to do about surface contaminations: the external hazard. In making this decision, we should keep in mind that complete decontamination of surface radioactivity is not necessary. It is only necessary that the radioactivity be reduced below permissible levels, say, 5 mrem/hr. If, after a health physics survey, the surface contamination is higher than this level, one of four alternate decisions (or a combination of all) must be made. These alternatives are:

(1) Wait it out	(natural decay)
(2) Scrub it off	(acid washing)
(3) Seal it in	(lead painting)
(4) Throw it away	(replace with spares)

If the decision is to "scrub it off," the next fundament (this is number five, now) is to determine whether the decontamination must be done in place (e.g., piping, conduiting, machinery casings, etc.) or whether some of the items can be removed (e.g., valves, instruments, servocomponents, machinery). In-place surface decontamination can be done by

Table 14-11. Typical "Scrubbing Treatment" for Decontaminating Surfaces of Materials

Material	Treatment
Stainless steel	HNO_3 washes of varying concentrations and temperatures, followed by Na_2CO_3
Mild Steel	10% citric acid, 5% soap powder, using stiff brushes, followed by rinsing
Lead	HCl, plenty of rinse water; watch out for lead-acid fumes
Brass	Acetone wipes, emery cloth, ammonium citrate, trisodium phosphate; wipe with absorbing tissues
Aluminum	10% HNO_3 with vigorous brushing, synthetic detergents
Glass	Soaked for several days in 60% HNO_3, followed by sulphuric-chromic acid solution
Plastics	Wiped with acetone and emery cloth
Concrete	Stiff brushing with scouring powder, soap and water; citric acid, trisodium phosphate, chipping, sandblasting
Wood	Sanding and planing
Tools	Boiled in 10% citric acid and 5% soap powder; scrubbed and rinsed
Machine parts	Soaked in 10% citric acid; smeared with NaOH paste; removed with hot water under pressure; scrubbed and rinsed

Note: Best all-around decontamination solution is 30% nitric acid, 10% oxalic acid, and varying mixtures of caustic soda and tartaric acid.

Ref: AECU-817 "Lecture Notes; Health Physics Training Lectures", Sept., 1950, pp. 92-93.

vacuum blasting (using wet abrasives), vacuum washing (using alternate acid and caustic washes), or ultrasonic equipment which shakes out the contaminants from the pores of materials. Here, also, provision for collecting and disposing of the decontaminants must be provided.

In the case of contaminated items which are removable, decontamination (fundament six) would be done in a so-called "glove box" (see Fig. 14-8). This is a bench-mounted decontamination chamber with viewing window, manipulating gloves, air lock, wash-down facilities (see Table

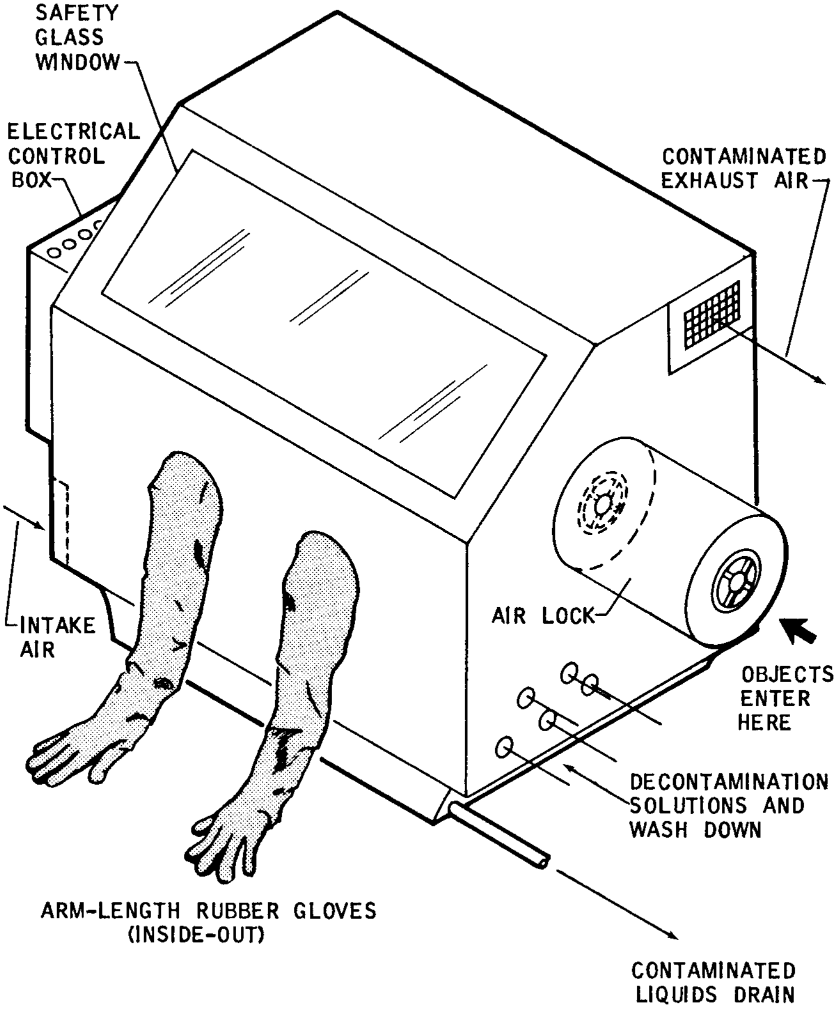

Fig. 14-8 Representative "Glove Box" for Decontaminating Small Items

14-11 for scrub treatments), sump, and lighting and ventilation. The use of a glove box is an effective and flexible method of decontamination and may turn out to be one of the most used pieces of health physics equipment aboard a nuclear ship. Among other things, it is useful for decontaminating radiation instruments and for decontaminating decontamination equipment.

14-10 Administrative and Legal Reports

Following any radiation incident or overexposure of personnel, there would be administrative and legal reports galore. The nuclear shipping company management would want reports, as would insurance underwriters, maritime labor unions, port authorities, medical authorities, federal agencies, attorneys and courts. All would want these radiation reports on their own separate forms. Indeed, the burden of administrative and legal reporting could jeopardize a sound and intelligent health physics program.

The administrative necessity for reporting the circumstances of radiation accidents, disposal of radioactive wastes, and personnel exposures cannot be contested. However, the number and variety of forms can be contested. Already—without any government or legal edict—there has arisen a disturbing number of health physics reports (see Table 14-12). These are "self-administered" by health physics organizations in nuclear plants ashore. Add to this list the administrative requirements of federal and municipal agencies regulating merchant ships, and it (the Table 14-12 list) could grow many-fold. Like the ship safety certification of Sec. 13-14, one wonders if there isn't a new approach—a new philosophy—to this report-form business. Why not some universal form recognized and accepted by all?

Table 14-12. Some Typical "Self-Administered" Health Physics Reports

- Cumulative Exposure of Personnel
- Notification of Overexposure
- Special Exposure Record
- Visitor's Log (Reactor Plant)
- Personnel Dosimeter Control Card
- Radiation Survey Report
- Instrument Calibration Record
- Collection/Disposal of Radioactive Wastes
- Radiation Area Location Log
- Radiation Accident Report
- Routine Radiation Level Inspection
- Report on Waste Disposal Survey

In a radiation incident, say, there are only so many facts that can be reported on—date, time, place, radiation level, type of radiation, radioactive species, decontamination procedures, residual radiation, instrument calibration, etc. True, not everyone wants or needs to know all of this information. But, even so, it could all be put down; then let the user of the information pick what he wants. Instead of myriads of piecemeal reports, one complete report . . . for each type of radiation incident.

There are three types of radiation incidents. So, if the above philosophy were pursued, there need be only *three* official reports of health physics origin. These would be (for nuclear ships):

(1) Report of Radiation Accident
(2) Report of Disposal of Radioactive Wastes
(3) Record of Personal Exposure to Radiation

The accident report would be made only when radiation exceeded permissible design limits. The disposal report would be a cumulative record of all radioactive wastes disposed from the nuclear ship. The personnel record would be a running tally of all exposures received by each mariner, with any overexposures suitably flagged . . . and explained. Beyond these three reports, all other information could be entered as appropriate in the Health Physics Log, the Engine Room Log, or the Ship's Official Log. Then, pertinent extractions from these logs could be made for special reporting purposes.

Sooner or later, the legality of nuclear ship report forms, and the accuracy of the information they contain, will be challenged. A nuclear ship passenger may claim that radiation exposure caused his hair to turn grey and warts to appear on his hands. He may sue the nuclear ship operator for "damages." A seaman may develop lung cancer, anemia, eye cataract, or other malady, and he, too, may claim damages. In the legal contests, the concept of "permissible" exposures may be challenged; the validity of film badge and personnel dosimetry records may be questioned. Charges of negligence and problems of indemnification would arise.

In most legal proceedings to date, the stipulation of a "technically qualified person" is made.* Such a person, presumably a health physicist, is responsible for safe interpretations of permissible exposures and for the use and calibration of radiation instruments for measuring these exposures. It appears reasonable, therefore, that the licensing and certificating of health physics personnel would become a legal as well as a safety requirement for nuclear ship operations.

SUMMARY

We recognize that "health physics" comprises a group of radiation housekeeping functions that back up the design and regulatory safeguards of a nuclear ship. Health physics functions are new undertakings for merchant ships, and, therefore, new personnel and new organizational concepts are required.

Health physics duties include keeping records of personnel radiation exposures, routine checks of reactor plant monitoring and radiation safety equipment, calibration of radiation instruments, making surveys in event of radiation accidents, prescribing decontamination procedures, and other related activities at

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* Ref: "Administrative Problems in Radiation Protection," Tabershaw and Harris, *Nucleonics*, Dec., 1954, pp. 8-13.

sea and in port. To carry out these responsibilities, technically qualified personnel are required, as are adequate equipment and facilities.

Actually, nuclear radiation is no more dangerous to operating personnel than other hazards aboard ship, so long as proper precautions are taken. Probably the worst consequence would be an overexposure of human hands, over many years of operating time. This could result in shininess, leatheriness, cracks, and wartlike protuberances here and there on the hands. But even from this, recovery is possible. If there is prolonged overexposure of the head and face, injury to brain cells and eye lenses could be permanent. However, such injuries can be minimized by protective head gear and by employing persons over 45 years of age.

We should keep in mind that radiation which is an external health hazard is measured in mrem, while that considered to be an internal health hazard is measured in μC. External health hazards are generally fixed, and hence, do not move on their own. People are safe through distances. Internal health hazards are loose and move around in the form of airborne or liquidborne contaminants. If once inside the human body, distance is no longer a safety factor.

Health physics implies the capability of surveying any radiation incident with various types of hand-carrying and bench-type instruments. A radiation "instrument" consists of a sensing element, electronic circuitry, and a readout device. The sensing elements operate on one of three basic principles, namely: (1) the ionization principle, (2) the scintillation principle, or (3) the coating principle (for neutrons). Health physicists are responsible for the care and calibration of these instruments directly aboard ship.

In the event of a radiation incident—meaning when the radiation level exceeds normal permissible limits—the major consequences are contaminated surface, air, and liquid materials in the vicinity of the incident. The principal difficulty is discovering the location of the incident before it is spread around unknowingly. To avoid this all personnel going off watch are monitored; the radiation areas are surveyed and marked off. After confining particularly the airborne contaminants, preparations are made for decontamination.

The first fundament of decontamination is to think out what to do; then, secondly, prepare and instruct decontamination personnel. The third fundament is to clean up all loose contaminants, using special vacuum equipment and sealed containers for this purpose. A fourth fundament is to decide what to do about surface contamination: either wait it out, scrub it off, seal it in, or throw it away. The fifth fundament is to disconnect movable items and send them to a decontamination "glove box." Sixth, those items which cannot be disconnected are vacuum blasted, vacuum washed, or ultrasonically decontaminated in place.

All aspects of health physics work involve administrative and legal reports. The information in these reports affects the health and safety of people and, therefore, the information must be accurate and complete. Legal contestations may probe into the preparation of these reports by "technically qualified persons." Presumably this means health physicists. A nuclear ship with health physicists aboard, therefore, would satisfy legal as well as safety requirements.