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Exam Preview:

1. The process of breaking a neutral atom or molecule into electrically charged parts is called ionization. This process requires energy.
    a. True
    b. False
2. The mass of an alpha particle is about ____ times the mass of a single neutron or proton and has a positive charge of +2. This positive charge causes the alpha particle to ionize nearby atoms as it passes through body tissue.
    a. 2
    b. 4
    c. 6
    d. 10
3. All chemical reactions involving hydrogen can also be performed with tritium, sometimes at a higher rate if the tritium concentration is high enough to catalyze the reaction.
    a. True
    b. False
4. According to the reference material, a neutron has about 2,000 times the mass of an electron, but only ___ the mass of an alpha particle.
    a. 3/4
    b. 5/8
    c. 1/2
    d. 1/4

5. Prolonged exposures can be expected to affect the biological half-life. Tritium's interaction with organic hydrogen can result in additional half-life components ranging from 21 to 30 days and _____ days.
    a. 100 to 300
    b. 150 to 400
    c. 200 to 500
    d. 250 to 550
6. According to the reference material, intake of gaseous tritium through the skin has been found to be much more harmful compared with that from inhalation.
    a. True
    b. False
7. Skin absorption of airborne HTO is also important, especially during hot weather, because of the normal movement of water through the skin. For skin temperatures between _____degrees C, the absorption of HTO is about 50% of that for HTO by inhalation.
    a. 20 and 30
    b. 25 and 35
    c. 30 and 40
    d. 35 and 45
8. According to the reference material, the committed dose following an HTO exposure is directly proportional to the biological half-life, which in turn is inversely proportional to the turnover rate of body water. Although the average biological half-life is 10 days, it can be decreased by simply increasing fluid intake, especially diuretic liquids such as coffee, tea, beer, and wine.
    a. True
    b. False
9. Studies of biological elimination rates of body water in humans date back to 1934, when the body water turnover rate was measured using HDO. A simple average of the data suggests a value of ___ days for the measured biological half-life of water in the body with a deviation of ±50%.
    a. 9.5
    b. 10
    c. 11.5
    d. 15
10. After HTO enters the body, it is quickly distributed throughout the blood system and, within _____ hours, throughout all water in the body. Once equilibrium is established, the tritium concentration is found to be the same in samples of blood, sputum, and urine.
    a. 4 to 5
    b. 3 to 4
    c. 2 to 3
    d. 1 to 2

ACRONYMS

AEA	Atomic Energy Act of 1954
AI	Alveolar-Interstitial region
ALARA	As Low As Reasonably Achievable
ALI	Annual Limit on Intake
AMAD	Activity median aerodynamic diameter
AMD	Activity median diameter
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASN	French Nuclear Safety Authority
ANSI	American National Standards Institute
ARAR	Applicable or Relevant and Appropriate (CERCLA)
AU	Office of the Associate Under Secretary for Environment, Health, Safety and Security
AWQC	Ambient water quality criteria
bb	bronchiolar region
BB	Bronchial region
Bq	Becquerel
BS	Bone surface
BTSP	Bulk Tritium Shipping Package
BZA	Breathing zone air (sampler)
CANDU	CANada Deuterium Uranium pressurized reactor
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
Ci	Curie
CMD	Count median diameter
CoC	Certificate of Compliance
CRC	Combustion Research Center
CWA	Clean Water Act
DCS	Derived Concentration StandardD&D Decontamination and Decommissioning
DAC	Derived Air Concentration
DBA	Design Basis Accident
DBE	Design Basis Earthquake
DCF	Dose Conversion Factor
DCF_o	Dose Conversion Factor based on observed activity
DCG	Derived Concentration Guide
DNFSB	Defense Nuclear Facilities Safety Board
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation

DPM	Disintegrations per minute
DSA	Documented Safety Analysis
E_{50}	Committed Effective Dose
EDL	Economic Discard Limit
EPCRA	Emergency Planning and Community Right-to-Know Act
EPDM	Ethylene Propylene Diene Monomer
EPA	Environmental Protection Agency
EH	Office of Environment, Safety and Health
EIS	Environmental Impact Statement
EM	Office of Environmental Management
ET	Extrathoracic
f_1	fraction of radionuclide absorbed from the GI tract
FCA	Fire Control Area
FDTAS	Field Deployable Tritium Analysis System
FY	Fiscal Year
GI	Gastrointestinal
HEPA	High-Efficiency Particulate Air
HDPE	High-Density Polyethylene
HIVES	Highly Invulnerable Encased Safe
HMR	Hazardous Material Regulations
HSV	Hydride Storage Vessel
HSWA	Hazardous and Solid Waste Amendments
HTV	Hydride Transport Vessel
HVAC	Heating, Ventilation, and Air Conditioning
IAEA	International Atomic Energy Agency
IATA	International Air Transport Association
ICRP	International Commission on Radiological Protection
IMT	Insoluble Metal Tritide
INL	Idaho National Laboratory
ISM	Integrated Safety Management
ITER	International Thermonuclear Experimental Reactor
ITP	Insoluble Tritiated Particulate
keV	Kiloelectron volt
LANL	Los Alamos National Laboratory
LDPE	Low-Density Polyethylene
LDR	Land Disposal Restriction
LLD	Lower Limit of Detection
LLI	Lower Large Intestine
LLNL	Lawrence Livermore National Laboratory
LN	Lymph Node
LSA	Low Specific Activity
LSC	Liquid Scintillation Counting

LLW	Low-level waste
MAR	Material at Risk
mCi	Millicurie
MCL	Maximum Contaminant Level
mm	Millimeter
mrem	Millirem
NFPA	National Fire Protection Association
NMMSS	Nuclear Materials Management and Safeguards System
NNSS	Nevada National Security Site
NP	Nasal Passage Region
NPDWR	National Primary Drinking Water Regulation
NPH	Natural Phenomena Hazard
NRC	U.S. Nuclear Regulatory Commission
NRPB	National Radiological Protection Board
OBT	Organically Bound Tritium
OPI	Office of Primary Interest
ORR	Operational Readiness Review
OH-	Hydroxide
P	Pulmonary Parenchyma Region
PC	Performance Category
PCB	Polychlorinated biphenyl
PMR	Palladium Membrane Reactor
PPE	Personal Protective Equipment
PPPL	Princeton Plasma Physics Laboratory
psia	pounds per square inch absolute
psig	pounds per square inch gauge
PSO	Program Secretarial Officer
PTFE	Polytetrafluoroethylene
PVC	Polyvinyl chloride
PV	Product Vessel
RCRA	Resource Conservation and Recovery Act
RCS	Radiological Control Standard
RM	Remainder Organ
RMA	Radioactive Materials Area
RTF	Replacement Tritium Facility
RWP	Radiological Work Permit
S	Stomach or specific source organ (used with SEE)
SAES	Societá Apparecchi Elettrici e Scientifici
SAF	Self Absorption Factor
SAM	Surface Activity Monitor
SAR	Safety Analysis Report
SCO	Surface Contaminated Object

SDWA	Safe Drinking Water Act
SEE	Specific Effective Energy
SEL	Seismic Equipment List
SEM	Scanning Electron Microscope
SEP	Seismic Evaluation Procedure
SI	Small Intestine
SMT	Stable Metal Tritide
SNL	Sandia National Laboratory
SNLL	Sandia National Laboratory, Livermore
SNM	Special Nuclear Material
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
SSCs	Structures, Systems, and Components
STC	Special Tritium Compound
Sv	Sievert
T	Tissue
TB	Trachea and Bronchial Region
TFG	Tritium Focus Group
TRL	Tritium Research Laboratory, Sandia National Laboratory
TWD	Technical Work Document
TSD	Treatment, Storage, and Disposal
TSR	Technical Safety Requirement
UB	Urinary Bladder
UHMWPE	Ultra-High-Molecular-Weight Polyethylene
ULI	Upper Large Intestine
WETF	Weapons Engineering Tritium Facility, Los Alamos National Laboratory
WSRC	Washington Savannah River Company

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INTRODUCTION

This Primer is designed for use by operations and maintenance personnel to improve their knowledge of tritium safe handling practices. It is applicable to many job classifications and can be used as a reference for classroom work or for self-study. It is presented in general terms so that it can be used throughout the DOE Complex.

The information in this Primer should enable the reader to do the following:

- Describe methods of measuring airborne tritium concentration.
- List the types of protective clothing that are effective against tritium uptake from surface and airborne contamination.
- Name two methods of reducing the body dose after a tritium uptake.
- Describe the most common method for determining the amount of tritium uptake in the body.
- Describe the steps to take following an accidental release of airborne tritium.
- Describe the damage to metals that results from absorption of tritium.
- Explain how washing hands or showering in cold water helps reduce tritium uptake.
- Describe how tritium exchanges with normal hydrogen in water and hydrocarbons.

The organization of the Primer is as indicated in the Overview. The following section contains background information on "Radiological Fundamentals." Those familiar with these topics may elect to skip this section and begin reading at the section entitled "Physical and Chemical Properties of Tritium." Additional information about tritium is available from the sources listed in the "Bibliography" section.

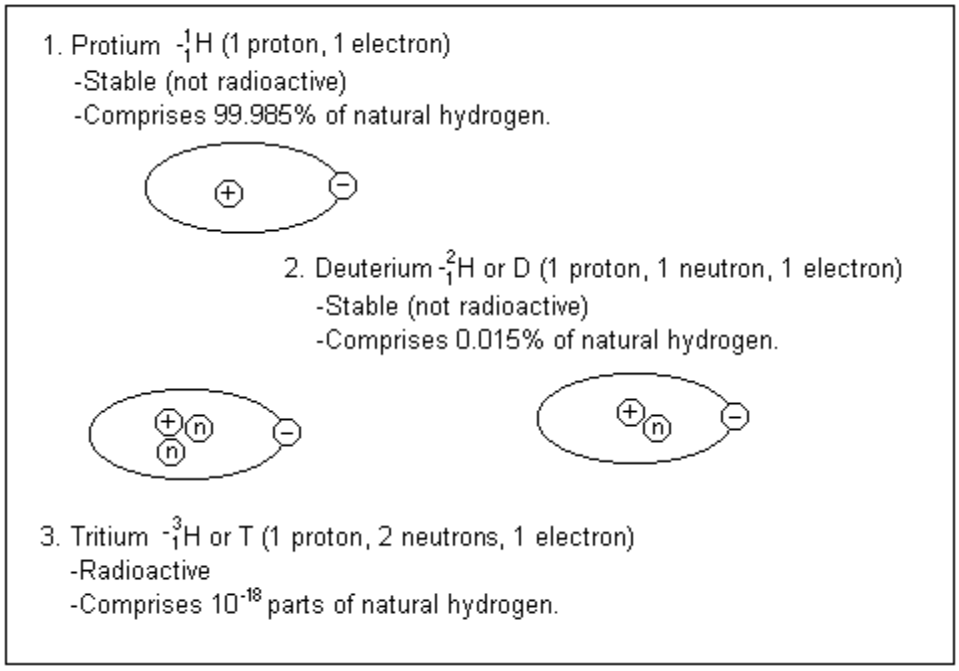
RADIOLOGICAL FUNDAMENTALS

This section provides a review of radiological fundamentals. The reader is assumed to be familiar with this information from radiological worker training. The section discusses hydrogen and its isotopes and describes basic radiological concepts.

Hydrogen and Its Isotopes

Atomic nuclei of a particular element (such as hydrogen or oxygen) have the same number of protons (positively charged), but may have a different number of neutrons (no net charge). Those that have a different number of neutrons are isotopes of that element. Most elements exist in nature in several isotopic forms. For example, hydrogen has one proton. The isotopes of hydrogen either have no neutrons (normal hydrogen, called protium), one neutron (deuterium), or two neutrons (tritium) (Figure G-1). Although isotopes of an element have almost the same chemical properties, the nuclear properties can be quite different.

Figure G-1: Hydrogen Isotopes



Nuclear notation uses the chemical symbol (H for hydrogen) and an arrangement of subscripts and superscripts. The total number of protons and neutrons is shown as a superscript: ^{1}H for protium, ^{2}H for deuterium, and ^{3}H for tritium. The number of protons (which identifies the element) is shown as a subscript. However, the common practice of using H, D, and T for these isotopes, respectively, will be followed in this document, except where nuclear reactions are illustrated.

The atomic masses, symbols, and natural abundances of the three isotopes of hydrogen are given in Table G-1.

Table G-1: Hydrogen Isotopes

Symbol				
Physical	Common	Name	(%) Natural Abundance	Mass (mass units)
$^{1}_{1}H$	H	Protium	99.985	1.007825
$^{2}_{1}H$	D	Deuterium	0.015	2.01400
$^{3}_{1}H$	T	Tritium	1×10^{-18}	3.01605

Sources of Tritium

Tritium occurs naturally in the environment. Reactions between cosmic radiation and gases in the upper atmosphere produce most of the world's natural tritium. For example,

Tritium converts into water and reaches the earth's surface as rain. An estimated production rate of 4 × 10^6 Ci/yr results in a world steady-state natural inventory of ~70 × 10^6 Ci[104].

In addition, commercial producers of radioluminescent and neutron generator devices release about 1 × 10^6 Ci/yr. Atmospheric nuclear test explosions from 1945 to 1975 added about 8 × 10^9 Ci of tritium to the environment, much of which has since decayed. However, about 5 × 10^8 Ci remain in the environment, mostly diluted in the oceans. Underground nuclear tests appear to add little tritium to the atmosphere. The nuclear power and defense industries now release 1-2 × 10^6 Ci/yr, a small fraction of which comes from light-water reactors. Tritium is also a by-product of light-water and heavy-water nuclear reactor operation. In their coolants, these reactors produce about 500 to 1,000 and 2 × 10^6 Ci/yr, respectively, for every 1,000 MW(e) of power. Tritium is a fission product within nuclear fuel, generated at a rate of 1-2 × 10^4 Ci per year/1000 MW(e). U.S. DOE reactors have produced tritium by the neutron bombardment of lithium (Li).

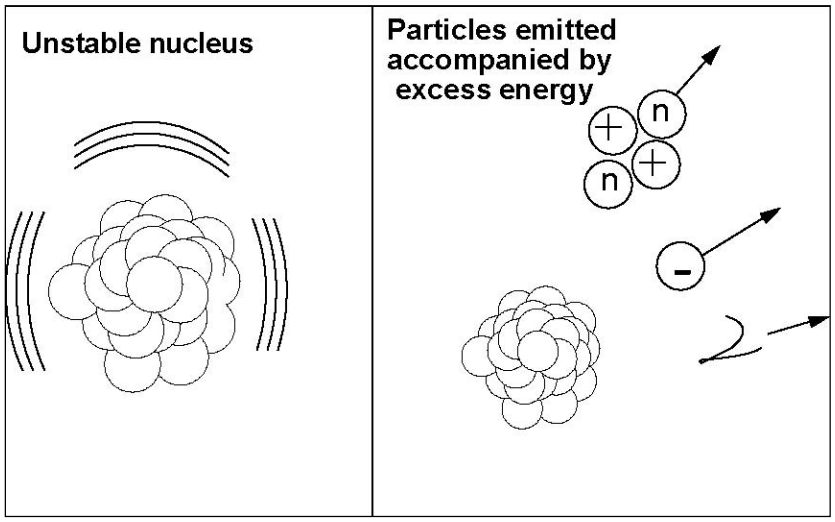
Stable and Unstable Nuclides

In the lighter elements, the ratio of neutrons to protons in their stable nuclei is usually 1 (one neutron for every proton). For the heavier elements, this ratio gradually increases to about 1.5 (1.5 neutrons for every proton). Although one cannot always predict from its ratio whether an isotope is stable or unstable, the relationship between the number of protons and neutrons is extremely important.

When an isotope is unstable, its nucleus will emit rays or particles or it may split into two different nuclei. Some combinations of neutrons and protons lead to stable nuclei. If there are too many or too few neutrons, the resulting nucleus is not stable. This unstable nucleus tries to become more stable by releasing excess energy. Atoms with unstable nuclei are radioactive. The process of nuclei releasing this energy is referred to as radioactive decay or disintegration (Figure G-2). If a nucleus is still unstable after radioactive decay, further decay will occur.

[104]The curie (Ci) is a unit of activity defined as 3.7×10^{10} disintegrations per second (dps). A more basic unit is 1 dps, which is the definition of the becquerel (Bq). Throughout this Primer, the curie will be used instead of the becquerel.

Figure G-2: Radioactive Decay

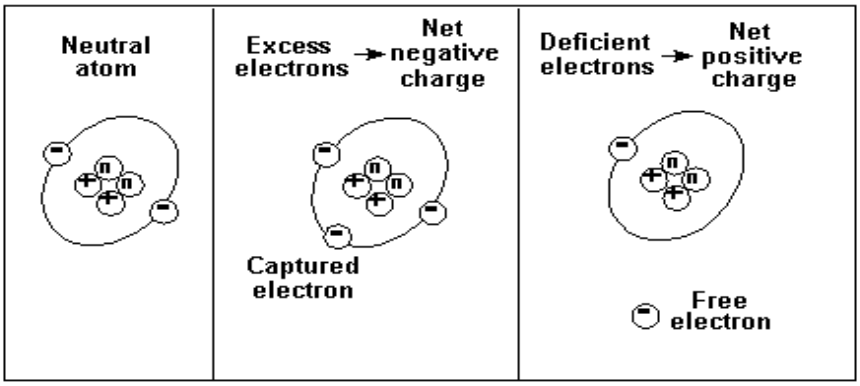


Ions and Ionization

Atoms can combine chemically to form molecules. Atoms and molecules are surrounded by orbiting electrons (negatively charged). If the number of electrons equals the total number of protons (positively charged) in the nucleus, the atom or molecule is neutral (uncharged).

Electrically charged atoms or molecules are called *ions*. Ions are either positively or negatively charged, depending on the number of orbiting electrons relative to the number of protons in the nucleus. As shown in Figure G-3, ions with more electrons than protons are negatively charged, while ions with more protons than electrons are positively charged. The process of breaking a neutral atom or molecule into electrically charged parts is called *ionization*. This process requires energy. Ionization removes electrons from the atom, or molecule, leaving an ion with a positive charge. The negatively charged electron (which can attach itself to a neutral atom or molecule) and the positively charged ion are called an ion pair. Radiation that causes ionization is called *ionizing radiation*.

Figure G-3: Neutral and Ionized Atoms



Types of Radiation

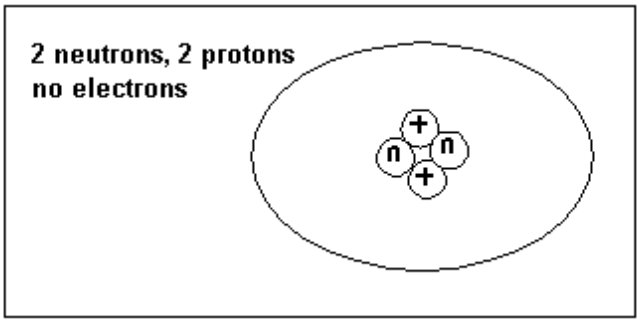
There are four basic types of ionizing radiation emitted from nuclei: alpha particles, beta particles, gamma rays, and neutrons.

- **alpha** particle (α)—consists of two protons and two neutrons and is the same as the nucleus of a helium atom (${}_{2}^{4}He$) (Figure 4). Generally, only the heavy nuclides can emit alpha particles.

A typical example of an α -emitting nuclide is uranium-238:

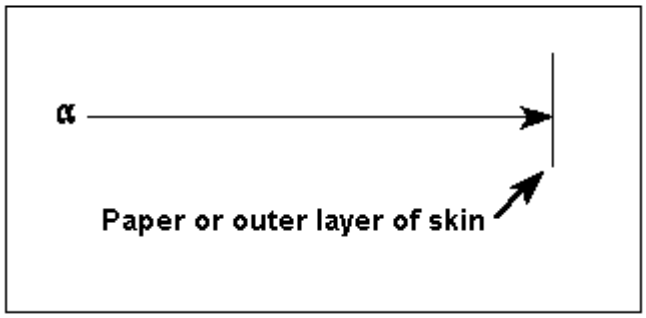
$${}_{92}^{238}U \rightarrow {}_{90}^{234}Th + \alpha + \text{energy.}$$

Figure G-4: Alpha Particle



The mass of an alpha particle is about four times the mass of a single neutron or proton, and has a positive charge of +2 (it has no electrons). This positive charge causes the alpha particle (2 neutrons, 2 protons 0 electrons) to ionize nearby atoms as it passes through body tissue. The strong positive charge and its relatively slow speed (resulting from its large mass) causes the alpha particle to interact strongly with orbiting electrons of atoms and molecules and to lose large amounts of energy in a short distance. This limits the penetrating ability of the alpha particle, making it easy to stop. A few centimeters of air, a sheet of paper, or the outer layer of skin stops alpha particles (Figure G-5).

Figure G-5: Alpha Shielding



Alpha particles are not an external radiation hazard because they are easily stopped by protective clothing or the outer layer of skin. However, if an alpha emitter is inhaled or ingested, it becomes an internal radiation hazard. Because the source is in close contact with body tissue, the alpha particle will dissipate its energy in a short distance of the tissue.

- **beta particle** (β) is equivalent to an electron except for its source. Beta-emitting nuclides have too many neutrons. A neutron emits a β particle, and the neutron is then converted to a proton. Tritium decay provides a good example of this process:

$$ {}_{1}^{3}H \rightarrow \beta + {}_{2}^{3}He + \text{energy.} $$

A β particle is identical to an electron, and its mass and charge are the same as those of an electron. As in the case of alpha particles, beta particles ionize atoms by removing electrons from their orbits. This reaction occurs from charged particle interactions or "collisions" with orbiting electrons.

Beta particles penetrate further than alpha particles of the same energy. A high-energy beta particle can penetrate a few centimeters of organic tissue. The higher the energy is, the greater the penetrating ability. However, low-energy beta particles of tritium can be shielded by skin, paper, or only about 6 mm of air.

- **gamma ray** (γ) is emitted when the nucleus of a nuclide releases stored energy without releasing a particle. Many gamma-emitters are found among the products of nuclear fission.

During pure γ emission the nucleus does not emit particles or change its nuclear structure or chemical characteristics. For instance,

$$ {}_{Z}^{A}X \rightarrow \gamma + {}_{Z}^{A}X . $$

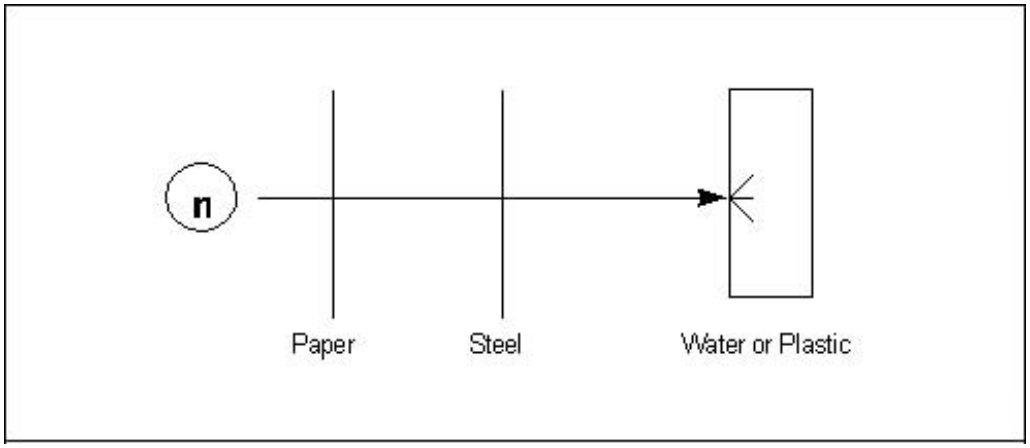
Gamma radiation is in the form of electromagnetic waves (or photons). Gamma rays are similar to x-rays, but they differ in their origin and energy. Gamma rays originate within the nucleus, and x-rays originate outside the nucleus.

Gamma rays have a very high penetrating power because they have no charge or mass. Depending on their energy, a stream of gamma rays may penetrate with gradually diminishing intensity through several inches of concrete or similar material. They can be shielded effectively by very dense materials, such as lead and uranium. Gamma rays are a whole-body hazard. That is, because of their penetrating ability, the damage caused by gamma rays is not restricted to any particular body organ.

- **neutron** (n)—may be emitted spontaneously by heavy nuclei during fission or may be emitted during radioactive decay. They are uncharged particles that have mass and a high penetrating ability.

A neutron has about 2,000 times the mass of an electron, but only one-fourth the mass of an alpha particle. Neutrons are difficult to stop because they lack a charge. Neutrons mainly interact with matter by striking hydrogen nuclei or interacting with the nucleus of atoms. These collisions generally cause charged particles or other radiation to be emitted. These particles may then ionize other atoms. Collisions between neutrons and hydrogen nuclei (protons) are effective in stopping or slowing down high-energy neutrons. Neutrons are best shielded by materials with a high hydrogen content, such as water or plastic (see Figure G-6).

Figure G-17 Neutron Shielding



Radioactivity

As radioactive isotopes decay, the number of radioactive nuclei decreases. The time required for half of the nuclei in a sample of a specific radioactive isotope to undergo decay is called its (physical) half-life (Figure G-7). Each radioactive isotope has its own characteristic half-life. Radioactive isotopes decay to less than 1% of their original quantity after about seven half-lives.

Half-lives vary widely with different radionuclides, as shown by the following examples:

^{16}N -7.35 seconds

^{3}H -12.43 years

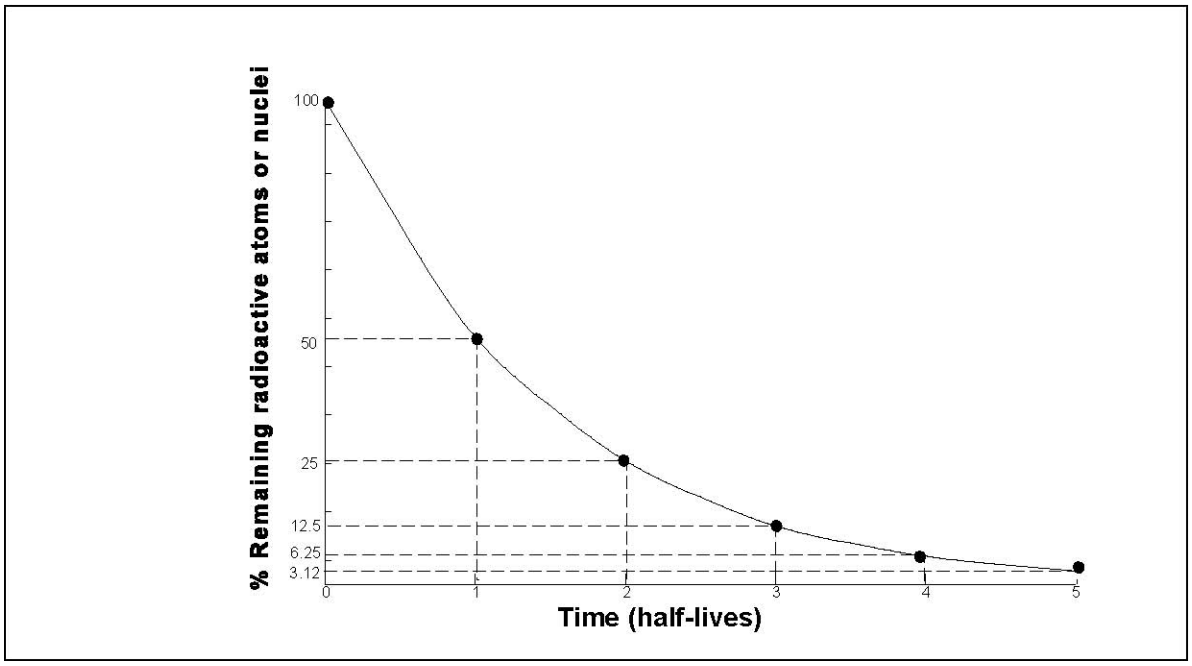
^{238}U -4.5×10^{9} years (4.5 billion years)

The activity of a radioactive isotope sample is defined as the number of nuclei that decay per unit of time.

It has been shown that for a pure radioactive isotope the number of nuclei decaying per unit time (rate of decay) is proportional to the number of nuclei available to decay. If the substance is not being replenished, its activity will decrease accordingly. Therefore, in terms of half-life, the remaining activity after a period of time can be expressed as follows:

$A_t = A_0 \times (1/2)^n$ or $A_0 / A_t = 2^n$

Figure G-7: Half Life



example where:

A_0 = the initial activity (Ci)
A_t = activity after elapsed time, t (Ci)
n = number of half-lives during elapsed time, equal to $t/T_{1/2}$,
t = elapsed time (time units)
$T_{1/2}$ = half-life (time units).
For example, assume we have stored 10,000 Ci of tritium.
How many curies will be left after 50 years of storage?
A_0 = 10,000 Ci; n = 50/12.43 = 4.02
$A_t = A_0 (1/2)^n$

$A_t = 10{,}000 (1/2)^{4.02}$

= 10,000 × 0.062
= 620 Ci (approximately)

PHYSICAL AND CHEMICAL PROPERTIES OF TRITIUM

This section reviews the nuclear properties of tritium and discusses some of the physical and chemical properties that are important in understanding tritium handling, containment, and contamination control.

Nuclear and Radioactive Properties

Being an isotope of hydrogen, tritium has many of the properties of ordinary hydrogen (such as chemical reactions, permeability, and absorption). Differences may occur because the decaying tritium atoms can speed up (catalyze) reactions of undecayed tritium, or because atoms that have undergone decay have changed into helium atoms (^{3}He). Additionally, small differences in chemical reaction rates may result from the relative masses of the isotopes.

Some of the useful properties of tritium are listed in Table G-2. Note that the properties listed are those of molecules of TT (or T2) i.e., two tritium atoms bound together. The specific activity and power density of HT (a hydrogen and tritium atom bound together) and DT (a deuterium and tritium atom bound together) are approximately one-half those for T2. The activity density of HT and DT is exactly one-half that of T2.

Table G-2: Important Nuclear Properties of Tritium

Half-Life	12.43 yrs
Specific Activity	9,545 Ci/g
Power Density	0.328 W/g
Activity Density	
(T_2 gas, 1 atm, 0 degrees C)	2.589 Ci/cm^3
(T_2 gas, 1 atm, 25 degrees C)	2.372 Ci/cm^3

Penetration Depths of Beta Particles

The penetration and absorption of beta particles in a material are important factors for detecting tritium and understanding the mechanisms by which tritium can degrade materials. A beta particle interacts with matter by colliding with electrons in the surrounding material. In each collision, the beta particle may lose several electron volts (keV)105 of energy, and the electron is stripped from its atom (ionization) or promoted to an excited state. The beta particle has a finite penetration depth that depends on its energy. Recall that tritium undergoes beta decay according to the following equation:

$$^{3}_{1}H \rightarrow \beta + {}^{3}_{2}He + \text{energy}$$

The helium daughter ($^{3}_{2}He$) is stable, but lighter than common helium ($^{4}_{2}He$). The decay energy is constant (18.6 keV), but is shared between the beta particle and an antineutrino (a tiny particle). The result is that not all beta particles have the same energy. The average energy is 5.7 keV. Consequently,

[105]An electron volt is a small unit of energy used in descriptions of nuclear and chemical reactions. It equals the energy gained by an electron when it moves across a potential of 1 volt.

not all tritium betas have the same penetration depth in a given material. Where beta ranges are given, it is customary to list both the highest energy and the average, most representative energy, as listed in Table G-3.

Table G-3: Penetration Depths of Tritium Betas

Material	E(β) (keV)	Penetration Depth
T_2 gas, STP[a]	5.7	0.26 cm
T_2 gas, STP	18.6	3.2 cm
Air, STP	5.7	0.036 cm
Air, STP	18.6	0.45 cm
Water, soft tissue (and oils/polymers of density ≈ 1)	5.7	0.42 µm
Water, soft tissue (and oils/polymers of density ≈ 1)	18.6	5.2 µm
Stainless steel	5.7	0.06 µm

a. STP = Standard temperature (0° C) and pressure (760 Torr).

With one unimportant exception, tritium is the weakest beta emitter known. The range of the most energetic tritium beta particles is only about 5 mm in air or 0.005 mm in water or soft tissue. This range makes it a nonhazard outside the body, but presents a detection problem. Where other radioisotopes can be detected by virtue of their penetrating radiation, tritium has to be introduced directly inside the detector or counter to be measured.

Chemical Properties

Laboratories that have large quantities of tritium usually handle it in the form of HT. However, at any time the tritium may be stored on metal getter beds (such as titanium, zirconium, or uranium). These beds form weak chemical compounds with hydrogen. Some of the beds are stable in air; and others are not and can only be used in certain atmospheres. The tritium is released (or delivered) by heating the beds to the required temperature.

Laboratories may also handle tritiated gases (such as ammonia and methane) and other compounds. By far the most common of these is HTO, which is formed from HT whenever it is exposed to oxygen or water vapor. The conversion reactions are oxidation and exchange:

oxidation

$2HT + O_2 \longrightarrow 2HTO$

$2T_2 + O_2 \longrightarrow 2TO_2$

exchange

$HT + H_2O \longrightarrow H_2 + HTO$

$T_2 + H_2O \longrightarrow HT + HTO$

These reaction rates are increased by radiation (from nearby tritium at high concentrations), heat, or the presence of metal catalysts (especially palladium or platinum). All chemical reactions involving hydrogen can also be performed with tritium, sometimes at a higher rate if the tritium concentration is high enough to catalyze the reaction. One of the most important reactions occurs when a tritium atom exchanges with a loosely bonded hydrogen atom of an organic molecule. However, where HT is dissolved in water (H2O), the exchange process is fairly slow because the hydrogen in is tightly bonded and the reaction is not catalyzed.

Contamination

Tritium as HT or HTO will readily adsorb onto the surface of most metals (such as stainless steel, copper, or aluminum), plastics, and rubbers. The tritium will remain fairly close to the surface unless the metal is heated to a high temperature. At room temperature, permeation into these metals is usually extremely slow.

In the case of metal contamination, the tritium remains on or very close to the surface. The contamination can be removed with water or water vapor if the surface is contaminated with HTO or with hydrogen (H_2 or D_2) if the contamination is HT. Heating also speeds up the decontamination process. The initial application of heat to surfaces can also be used to prevent or lessen the contamination by HT or HTO. Metal surfaces exposed to high pressures of HT or HTO for extended periods, especially at high temperatures, may allow enough penetration to cause structural damage to the metal. This is especially true if the decaying tritium causes a buildup of helium within the structure of the metal.

If adsorbed onto hydrogenous material, the tritium will easily permeate into the material. The HTO will move much more rapidly into the bulk material than will HT. The permeation rate varies with the type of material and is accelerated by increasing the temperature. As a result of this movement, plastics and rubbers exposed to tritium (especially as HTO) are readily contaminated deep into the bulk material and are impossible to decontaminate completely. After a period of time, the tritium exchanges with bulk hydrogen and presents little biological risk.

Highly contaminated metal or plastic surfaces may release some of the loosely-bound tritium immediately after exposure to the contaminating tritiated atmosphere or liquid. This is referred to as

outgassing. The personnel risk from outgassing tritium is generally much less than that from making unprotected skin contact with the outgassing surface.

BIOLOGICAL PROPERTIES OF TRITIUM

At most tritium facilities, the most commonly encountered forms of tritium are tritium gas (HT) and tritium oxide (HTO). Other forms of tritium may be present, such as metal tritides, tritiated pump oil, and tritiated gases such as methane and ammonia. As noted earlier, deuterated and tritiated compounds generally have the same chemical properties as their protium counterparts, although some minor isotopic differences in reaction rates exist. These various tritiated compounds have a wide range of metabolic properties in humans under similar exposure conditions. For example, inhaled tritium gas is only slightly incorporated into the body during exposure, and the remainder is rapidly removed (by exhalation) following the exposure. On the other hand, tritiated water vapor is readily taken up and retained in the body water. In this Primer, we will address only those compounds likely to be found at DOE laboratories: gaseous tritium, tritiated water, other tritiated species, metallic getters, and other tritiated liquids and gases.

Metabolism of Gaseous Tritium

During a brief exposure to tritium gas, the gas is inhaled and a small amount is dissolved in the bloodstream. The dissolved gas circulates in the bloodstream before being exhaled along with the gaseous waste products (carbon dioxide) and normal water vapor. If the exposure persists, the gas will reach other body fluids. A small percentage of the gaseous tritium is converted to the oxide (HTO), most likely by oxidation in the gastrointestinal tract. Early experiments involving human exposure to a concentration of 9 μCi/mL resulted in an increase in the HTO concentration in urine of 7.7 × 10-3 μCi/mL per hour of exposure. Although independent of the breathing rate, this conversion can be expressed as the ratio of the HTO buildup to the tritium inhaled as HT at a nominal breathing rate (20 L/min). In this context, the conversion is 0.003% of the total gaseous tritium inhaled. More recent experiments with six volunteers resulted in a conversion of 0.005%. For gaseous tritium exposures, there are two doses: (a) a lung dose from the tritium in the air inside the lung and (b) a whole body dose from the tritium gas that has been converted to HTO. The tritiated water converted from the gas in the body behaves as an exposure to tritiated water.

Intake of gaseous tritium through the skin has been found to be negligible compared with that from inhalation. Small amounts of tritium can enter the skin through unprotected contact with contaminated metal surfaces, which results in organically bound tritium in skin and in urine. Ordinarily this is not a serious problem because surfaces highly contaminated with tritium gas are inaccessible to skin contact. Also, most tritium exposed to air will be converted to the oxide form (water vapor) before the internal surfaces of equipment are handled during maintenance or repair operations.

Metabolism of Tritiated Water

The biological incorporation (uptake) of airborne HTO can be extremely efficient: up to 99% of inhaled HTO is taken into the body by the circulating blood. Ingested liquid HTO is also almost completely absorbed by the gastrointestinal tract and quickly appears in the blood stream. Within minutes, it can be found in varying concentrations in the organs, fluids, and tissues of the body. Skin absorption of airborne HTO is also important, especially during hot weather, because of the normal movement of water through the skin. For skin temperatures between 30 and 40 degrees C, the absorption of HTO is about 50% of that for HTO by inhalation (assuming an average breathing rate associated with light work, 20 L/min). No matter how it is absorbed, the HTO will be uniformly distributed in all biological fluids within one to two hours. This tritium has a retention that is characteristic of water. In addition, a small fraction of the tritium is incorporated into easily exchanged hydrogen sites in organic molecules. Hence, retention of tritiated water can be described as the sum of several terms: one characteristic of body water, and one or more longer-term components that represent tritium incorporated into organic hydrogen sites.

Metabolism of Other Tritiated Species

Most tritium handled in laboratories is in the form of tritiated gas or tritium oxide. However, tritium handling operations may form other compounds, such as tritiated hydrocarbons and metal tritides. Tritium may also contaminate surfaces and liquids such as pump oil. These materials may present special safe handling problems.

Metallic Getters

Although many metals are commonly used for gettering (chemically combining with) tritium, little information on their metabolic properties is available. Some of these compounds (such as uranium tritide and lithium tritide) are unstable in air. For these, exposure to air produces different results. Uranium tritide, being pyrophoric, releases large quantities of tritiated water; lithium tritide, a hydroxyl scavenger, releases mostly tritium gas.

Tritides of metals (such as titanium, niobium, and zirconium) are stable in air. For particles of these tritides, the primary organ of concern is the lungs. Some of the tritium may leach out in the lung fluids and then be incorporated into the body water. These particles may also produce organically bound tritium from contact with lung tissue, which would further complicate the metabolic process. However, in laboratories where such tritiated metals are handled, the possibility for exposure to airborne particulates of these metals is extremely remote except in accident situations.

Tritiated Liquids

Next to HTO, the most common tritiated liquid is tritiated vacuum pump oil. Experience at DOE facilities has shown that the specific activities of pump oils can easily range from a few mCi/L to a few tens of Ci/L. The wide range in specific activities may result from variations in the tritium concentration and total throughput of tritium. Depending on the history of these pumps, the tritium may be found as HT, HTO, or tritiated hydrocarbons.

Next to pump oils, the next most common group is tritiated solvents. All solvents can be absorbed through the skin and are relatively volatile and toxic. The overall toxicity of tritiated solvents is usually dominated by the chemical nature of the solvent.

Other Tritiated Gases

If tritium is released in a nitrogen- or air-filled glovebox, other tritiated gases may be formed, such as ammonia and methane. The conversion of tritium to tritiated ammonia is small unless the tritium concentration is very high. The toxicity of these gases is not believed to be greater than that of tritium oxide.

Biological Half-Life of HTO

Studies of biological elimination rates of body water in humans date back to 1934, when the body water turnover rate was measured using HDO. Since that time, several additional studies have been conducted with HDO and HTO. A simple average of the data suggests a value of 9.5 days for the measured biological half-life of water in the body with a deviation of ±50%. Calculations based on total fluid intake indicate a similar value. This is reasonable because the turnover rate of HTO should be identical to that of body water. In other words, the biological half-life of tritium is a function of the average daily throughput of water.

The biological half-life of HTO has been studied when outdoor temperatures varied at the time of tritium uptake. The data suggest that biological half-lives are shorter in warmer months. For example, the 7.5-day half-life measured in southern Nigeria is not surprising because the mean outdoor temperature there averages 27 degrees C. In contrast, an average 9.5-day half-life was measured in North America, where the mean outdoor temperature averages 17 degrees C. Such findings are consistent with metabolic pathways involving sensible and insensible perspiration. As such, the skin absorption and perspiration pathways can become an important part of body water exchange routes. It is important to note that personnel who are perspiring will have a greater absorption of tritium from contact with tritiated surfaces. For planning purposes, it is customary to use an average half-life of 10 days. However, it is not used to calculate doses from actual exposures.

Prolonged exposures can be expected to affect the biological half-life. Tritium's interaction with organic hydrogen can result in additional half-life components ranging from 21 to 30 days and 250 to 550 days. The shorter duration indicates that organic molecules in the body retain tritium relatively briefly. The longer duration indicates long-term retention by other compounds in the body that do not readily exchange hydrogen or that metabolize more slowly. However, the overall contribution from organically bound tritium is relatively small, that is, less than about 5% for acute exposures and about 10% for chronic exposures. Methods used to compute the annual limits on intake of air and water specify only the body water component and include the assumption of a 10-day biological half-life, as mentioned above.

Bioassay and Internal Dosimetry

Exposure to tritium oxide (HTO) is by far the most important type of tritium exposure. The HTO enters the body by inhalation or skin absorption. When immersed in tritiated water vapor, the body takes in approximately twice as much tritium through the lungs as through the skin. Once in the body, it is circulated by the blood stream and finds its way into fluids both inside and outside the cells.

According to International Commission on Radiological Protection (ICRP), the derived air concentration (DAC)[106] for tritium gas (HT) and HTO are 200,000 µCi/m^3 and 20 µCi/m^3, respectively. The ratio of these DACs (10,000) is based on the fraction of the gas converted to HTO in the lines. During exposure to HT, a small fraction of the tritium exchanges in the lung and is transferred by the blood to the gastrointestinal tract where it is oxidized by enzymes. This process results in a buildup of HTO until the HT is removed by exhalation at the end of the exposure. The resultant dose from exposure to this HTO is roughly comparable to the lung dose from exposure to HT. Thus, the total effective dose from an HT exposure is about 10,000 times less than the total effective dose from an equal exposure to airborne HTO. For both HTO and HT exposures, a bioassay program that samples body water for HTO is essential for personnel monitoring at tritium facilities.

Sampling Schedule and Technique

After HTO enters the body, it is quickly distributed throughout the blood system and, within 1 to 2 hours, throughout all water in the body. Once equilibrium is established, the tritium concentration is found to be the same in samples of blood, sputum, and urine. For bioassay purposes, urine is normally used for determining tritium concentrations in body water.

Workers who may be or who have been exposed to tritium are normally required to submit urine samples for bioassay periodically. The sampling period may be daily, biweekly, or longer, depending on the potential for significant exposure.

Special urine samples are normally required after an incident or a work assignment with a high potential for exposure. After a possible exposure, the worker should empty the bladder 1 to 2 hours later. A sample taken after the bladder is emptied should be reasonably representative of the body water concentration. A sample collected before equilibrium is established will not be representative because of dilution in the bladder, or because of initial high concentration in the blood. However, any early sample may still be useful as a sign of the potential seriousness of the exposure.

A pure HT exposure is considered as a combination of a lung exposure from the HT and a whole body exposure from HTO. The HTO comes from the conversion of HT dissolved in the blood. The whole body dose can be determined as outlined above by analysis for HTO in the urine. Because the effective dose equivalents from the lung and whole body exposures are about equal, the total effective dose can be obtained conservatively by multiplying the HTO whole body dose by 2. However, in general, this is too conservative because a release of pure tritium gas with less than 0.01% HTO is highly unlikely. With only a slight fraction (~0.1%) of HTO in the air, the total effective dose is essentially the HTO whole body dose determined by bioassay.

[106]The DAC is defined as that concentration of an airborne material, which, if a worker were exposed to it for one working year (2,000 hours), would result in a dose of 5 rem to the whole body or 50 rem to any organ or tissue.

As noted above, tritium-labeled molecules in the skin result from contact with metal surfaces contaminated with HT. This form is associated with a longer half-life. Lung exposure to airborne metal tritides may also cause unusual patterns of tritium concentrations in body water because of the slow release of tritium to the blood stream. If such exposures are possible at the facility, it is good practice to follow the elimination data carefully and to look for organically bound tritium in the urine.

The results of the bioassay measurements and their contribution to the worker's dose and general health should be shared with the worker in a timely fashion.

Dose Reduction

The committed dose following an HTO exposure is directly proportional to the biological half-life, which in turn is inversely proportional to the turnover rate of body water. This rate varies from individual to individual. Such things as temperature, humidity, work, and drinking habits may cause rate variations. Although the average biological half-life is 10 days, it can be decreased by simply increasing fluid intake, especially diuretic liquids such as coffee, tea, beer, and wine. Even though the half-life may be easily reduced to 4 to 5 days in this way, a physician should be consulted before persons are placed on a regimen that might affect their health. Chemical diuretics require medical supervision because the resultant loss of potassium and other electrolytes can be very serious if they are not replaced. Such drastic measures can result in a decrease in half-life to 1 to 2 days. Even more drastic is the use of peritoneal dialysis or a kidney dialysis machine, which may reduce the half-life to 13 and 4 hours, respectively. Such extreme techniques should be used only in life-threatening situations involving potential committed dose equivalents that would exceed about 100 rem without any treatment. Based on a 10-day half-life, the committed dose for an intake of 1 mCi of HTO is approximately 67 mrem.

Individuals whose urine concentrations exceed established limits should stop work that involves possible exposure to radiation, whether from tritium or other sources. Work restrictions are suggested or imposed to make certain that the annual dose limits for workers are not exceeded. The operating group may impose stricter limits on their staff than those imposed by the health physics group. Depending on the number of workers available and the importance of the work to be done, doses can be managed to safe levels (from 5 to 100 μCi/L in urine).

Results of bioassay sampling should be given to workers who have submitted samples as soon as they are available. The results may be posted, or the workers may be notified personally. Moreover, the results should be kept in the workers' radiation exposure records or medical files. Like any other radiation exposure, any dose in excess of the limits specified by applicable regulations must be reported to DOE.

TRITIUM MONITORING

The tritium monitoring system at a tritium handling facility is critically important to its safe operation. Operators and others at the facility need to be informed of the status of the processes, the development of any leaks in the primary or secondary containments, or of any releases to the room or environment so that protective measures and corrective action may be taken quickly. The location and degree of surface contamination are equally important to prevent accidental uptakes of tritium by personnel.

In this section, the various techniques used to monitor for tritium in gases (including air), in liquids, and on surfaces will be discussed.

Air Monitoring

Fixed ionization chamber instruments are the most widely used instruments for measuring gaseous forms of tritium in laboratory and process monitoring applications. Portable ionization chamber instruments are also used to control contamination and to supplement fixed instrument measurements. Such simple devices require only an electrically polarized ionization chamber, suitable electronics, and a method for moving the gas sample through the chamber—usually a pump. Chamber volumes typically range from a tenth to a few tens of liters, depending on the required sensitivity. The output is usually given in units of concentration (typically $\mu Ci/m^3$) or, if a commercial electrometer or picoammeter is used, in current units that should be converted to those of tritium concentration. The following rule of thumb can be used to convert current to concentration: 10^{15} × current (amps)/chamber volume (liters) = concentration ($\mu Ci/m^3$). For real-time tritium monitoring, the practical lower limits of sensitivity range from 0.1 to 10 $\mu Ci/m^3$. External background radiation or the presence of radon can lower the sensitivity of the instrument.

For measurements of low concentrations, sensitive electrometers are needed. For higher concentrations (>1 mCi/m3 for example), the requirements on the electronics can be relaxed, and smaller ion chambers may be used. Smaller chambers also need less applied voltage. Because of a greater ratio of surface area to volume, residual contamination in the chamber is more likely and is called "memory." This residual contamination elevates the background chamber current. Response times for higher level measurements can be made correspondingly shorter. However, because small chambers and chambers operated at low pressures may have significant wall effects, the above rule-of-thumb may not apply. Such instruments would have to be calibrated to determine their response.

Although most ionization chambers are of the flow-through type that requires a pump to provide the flow, a number of facilities use "open window" or "perforated wall" chambers. These chambers, which employ a dust cover to protect the chamber from particulates, allow the air or gas to penetrate through the wall to the inside chamber without the need for a pump. These instruments are used as single point monitors to monitor rooms, hoods, gloveboxes, and ducts.

Differential Air Monitoring

Because HTO is more toxic than HT ~10,000, it may be desirable to know the relative amounts of each species following a significant release into a room or to the environment. In the case of stack monitoring, discrete samples of the stack effluent should be taken using bubblers or desiccants with a catalyst for oxidizing the HT. Another technique for differential monitoring uses a desiccant cartridge in the sampling line of an ionization chamber monitor. The result is a measurement of the HT concentration. Without the cartridge, the total tritium concentration is measured. Subtraction of HT from the total produces the HTO concentration. The technique may be used with two instruments or one instrument in which the desiccant cartridge is automatically switched in and out of the sampling line.

Another technique uses a semipermeable membrane tube bundle in the sampling line to remove the HTO (preferentially over the HT), which is directed to an HTO monitor. After removing the remaining HTO with another membrane dryer, the sampled air is directed to the HT monitor. Although this technique is slower than the one requiring a desiccant cartridge, it does not require a periodic cartridge replacement. Furthermore, it can be adapted to measure tritium in both species in the presence of noble gases or other radioactive gases by adding a catalyst after the HTO dryers, followed by additional membrane dryers for the HTO. However, because of its slow response, it is more suitable for effluent or stack monitoring than for room monitoring. Because significant releases into a room are quite rare, it is easier to treat any such release as one of HTO than use complicated techniques for continuous differential monitoring.

Discrete Air Sampling

Discrete sampling differs from real-time monitoring in that the sampled gas (usually air) and is analyzed for tritium content (usually by liquid scintillation counting). The usual technique is to flow the sampled air through either a solid desiccant (molecular sieve, silica gel, or Drierite) or water or glycol bubblers. For low-flow rates (about 0.1 to 1 L/min), bubblers may be used. Bubblers are more convenient for sampling, but are less sensitive than the solid desiccant cartridges if the water in the desiccant is recovered by heating. Glycol or water may be used, but glycol is preferred for long-term sampling. In any case, the collected water is then analyzed for HTO. For differential monitoring of HTO and HT, a heated catalyst (usually a palladium sponge) is used between the HTO desiccant cartridge or bubblers and the HT cartridge or bubblers. This is currently the preferred method for monitoring stacks for reporting purposes. In a different arrangement, palladium is coated on the molecular sieve in the HT cartridge to oxidize the HT into HTO, which is then absorbed by the molecular sieve. However, this technique is used primarily for environmental monitoring.

Another technique for sampling HTO in room air is to use a "cold finger" to freeze HTO out of the air. An alcohol and dry ice mixture in a stainless steel beaker works well. To determine the concentration, the relative humidity must be known. Another sampling technique is to squeeze a soft plastic bottle several times to introduce the air (containing the HTO) into the bottle. A measured quantity of water is then

introduced, and the bottle is capped and shaken. In a minute or less, essentially all the HTO is taken up by the water, which is then analyzed.

Other techniques involve placing a number of vials or other small specially designed containers of water, cocktail, or other liquid in selected locations in the area being monitored. After a period of time (usually a number of days), the liquid in the containers is analyzed. The result is qualitative (for open containers) to semiquantitative (for specially designed containers).

Process Monitoring

Ionization chambers are typically used for monitoring stacks, rooms, hoods, gloveboxes, and processes. The outputs can be used to sound alarms, activate ventilation valves, activate detritiation systems, and perform other functions. In general, it can be expected that stack, room, and hood monitors will require little nonelectronic maintenance (i.e., chamber replacement because of contamination). Under normal circumstances, the chambers are constantly flushed with clean air and are not exposed to high tritium concentrations. However, glovebox monitors can be expected to eventually become contaminated, especially if exposed to high concentrations of HTO. Process HT monitor backgrounds can also be expected to present problems if a wide range of concentrations (4 to 5 orders of magnitude) are to be measured.

Mass spectrometers, gas chromatographs, and calorimeters are the main instruments used for process monitoring. Because of their relative insensitivities, these instruments cannot detect tritium much below a few parts per million (Ci/m3). For this reason, the analytical results and the related health physics concerns must be interpreted carefully. It is not uncommon to find that samples showing no trace of tritium when analyzed on a mass spectrometer may actually have a concentration of several curies of tritium per cubic meter. In spite of their contamination problems, ionization chamber instruments are useful for measuring these lower concentrations and for providing instant indications of changing concentrations that are not possible with the more sophisticated instruments.

Surface Monitoring

Any material exposed to tritium or a tritiated compound has the potential of being contaminated. Although it is difficult to quantify tritium contamination levels, several methods are available to evaluate the extent of contamination, including smear surveys and off-gassing measurements. Good housekeeping and work practices are essential in maintaining contamination at acceptable levels.

For health or safety implications, an indication of loose, removable tritium contamination is more valuable than a measurement of the total surface contamination. Loose tritium can be transferred to the body by skin contact or inhalation if it becomes airborne. As a result, loose contamination is routinely monitored by smears, which are wiped over a surface and then analyzed by liquid scintillation or proportional counting.

The smears are typically small round filter papers used dry or wet (with water, glycol, or glycerol). Wet smears are more efficient in removing tritium, and the results are more reproducible, although the papers are usually more fragile when wet. However, results are only semiquantitative, and reproducibility within a factor of 2 agreement (for wet or dry smears) is considered satisfactory. Ordinarily, an area of 100 cm2 of the surface is wiped with the smear paper and quickly placed in a vial with about 10 mL of liquid scintillation cocktail, or 1 or 2 mL of water with the cocktail added later. The paper must be placed in liquid immediately after wiping because losses from evaporation can be considerable, especially if the paper is dry. The efficiency of the liquid scintillation cocktail is only slightly affected by the size of the swipe. Foam smears are also available commercially. These smears dissolve in most cocktails and do not interfere significantly with the normal counting efficiency.

Smears may be counted by gas-flow proportional counting. However, because of the inherent counting delays, tritium losses before counting can be significant. Moreover, counting efficiencies may be difficult to determine and may vary greatly from one sample to the next. Another drawback is potential contamination of the counting chamber when counting very "hot" smears. For all of these reasons, a liquid scintillation spectrometer is the preferred system.

An effective tritium health physics program should specify the frequency of routine smear surveys. Each facility should develop a routine surveillance program that may include daily smear surveys in laboratories, process areas, step-off pads, change rooms, and lunchrooms. In many locations within a facility, weekly or monthly routine smear surveys may be sufficient. The frequency should be dictated by operational experience and the potential for contamination. In addition to the routine survey program, special surveys should be made following spills or on potentially contaminated material being transferred to a less controlled area to prevent the spread of contamination from controlled areas.

The surface contamination levels acceptable for the release of materials from radiological areas may be found in the DOE Radiological Control Standard and DOE Order 5400.5.

Tritium Probes

In general, the total tritium contamination on a surface can be measured only by destructive techniques. When tritium penetrates a surface even slightly, it becomes undetectable because of the weak energy of its beta particles. With open-window probes operated in the Geiger Mueller (GM) or proportional regions, it is possible to measure many of the betas emitted from the surface. Quantifying that measurement in terms of the total tritium present is difficult because the history of every exposure is different. Consequently, the relative amounts of measurable and unmeasurable tritium are different.

Such monitoring probes are used to survey areas quickly before more careful monitoring by smears, or to monitor the smears themselves while in the field. The probe must be protected carefully from contamination. When monitoring a slightly contaminated surface after monitoring a highly contaminated one, contamination of the probe can be an immediate problem. Placing a disposable mask over the front face of the probe can reduce, but never eliminate this contamination, particularly if

the tritium is rapidly outgassing from the surface. Sensitivity of the instrument depends on many factors, but should be about 103 to 104 dpm/cm^2.

For highly contaminated surfaces (>1 mCi/100 cm^2), a thin sodium iodide crystal or a thin-window GM tube can be used to measure the characteristic and continuous x-rays (Bremsstrahlung) emitted from the surface as a result of the interaction of the beta particle with the surface material.

Off-Gassing Measurements

Off-gassing can be measured using one of two methods. The simplest method is to "sniff" the surface for airborne tritium using a portable or fixed tritium monitor. The most reliable method, however, uses a closed-loop system of known volume and a flow-through ionization chamber monitor. By placing the sample inside the volume and measuring the change in concentration over time, tritium off-gassing rates can be determined accurately on virtually any material. The initial off-gassing rate is the required value because the equilibrium concentration may be reached quickly in a closed volume, especially if the volume is small because of recontamination by the airborne tritium.

The uptake of tritium from off-gassing materials is difficult to predict. Off-gassing tritium that is readily measured indicates contaminated equipment that should not be released for uncontrolled use.

Liquid Monitoring

Liquid is almost universally monitored by liquid scintillation counting. The liquid has to be compatible with the cocktail. Certain chemicals can degrade the cocktail. Others may retain much of the tritium; still others result in a high degree of quenching. In addition, samples that contain peroxide or that are alkaline may result in chemiluminescence that can interfere with measuring. Such samples should first be neutralized before counting. Chemiluminescence and phosphorescence both decay with time. Phosphorescence, activated by sunlight or fluorescent lighting, decays in the dark in a few minutes (fast component) to several days (slow component). Chemiluminescence, the result of chemical interaction of sample components, may take days to decay at room temperatures, but takes only hours to decay at the cold temperatures of a refrigerated liquid scintillation spectrometer. Distillations may be necessary for some samples.

For rather "hot" samples, as may be the case for vacuum pump oils, Bremsstrahlung counting may be useful. This technique may also be useful for active monitoring of "hot" liquids. Liquids may be monitored actively with scintillation flow cells, which are often made of plastic scintillator material or of glass tubing filled with anthracene crystals. However, both types are prone to memory effects that result from tritium contamination. In addition, flow cells are also prone to contamination by algae or other foreign material that can quickly degrade their counting efficiency.

Airborne Tritium

Tritium released to room air moves readily with normal air current. The room or building ventilation system should be designed to prevent the air from being carried to uncontaminated areas, such as offices or other laboratories where tritium is not allowed. For that reason, differential pressure zoning is commonly used, and released tritium is directed outside through the building stack. In some newer facilities where the large quantities of tritium are being handled, room air cleanup systems are available for emergency use. Following a significant release, the room ventilation system is effectively shut down, the room is isolated, and cleanup of room air is begun.

Secondary Containment

The most important control for preventing a release of tritium to the room atmosphere is the use of containment around the source of tritium. This containment usually takes the form of a glovebox, which is then a secondary containment if the tritium is already contained within the process plumbing, which is the primary containment. Even if the tritium is on the outside surface of a piece of equipment and located inside the glovebox, through popular usage, the box is still referred to as the secondary containment.

Gloveboxes used for tritium work typically are made of stainless steel or aluminum and use gloves made of butyl, neoprene, or Hypalon. Windows are made of glass or Lexan. In order to reduce the amount of tritium released to the atmosphere, gloveboxes where significant quantities of tritium are handled incorporate detritiation systems that process the glovebox atmosphere and remove the tritium. These detritiation systems, including the room cleanup systems mentioned above, convert released HT to HTO and collect the HTO on a molecular sieve for later recovery or burial. Newer systems use metal getters that recover HT without resorting to oxidation. These getters, which can only be used in certain glovebox atmospheres, can be heated to release and recover the HT easily.

The atmosphere in the glovebox may be air, nitrogen, argon, or helium, depending on the type of activity in the box. Even in boxes with inert gas atmospheres, small amounts of moisture and oxygen exist. Any release of tritium gas in the box will eventually be converted to the oxide. As a result, the oxide will slowly diffuse through the gloves and contaminate their outside surfaces. For that reason, personnel using gloveboxes that have had tritium releases are required to wear one or more additional pairs of disposable gloves when working in the glovebox.

Glovebox monitors are used to alert personnel of a release in the box and may be used to activate a cleanup system or to increase the rate of the cleanup process. With releases of tritium in the box, the monitor chamber will eventually develop a memory from contamination, mainly by HTO. Heated monitor chambers are useful in minimizing contamination by HTO.

The relative pressure of the glovebox atmosphere is normally kept negative in order to prevent the gloves from hanging outside the box where passersby may brush against them and to prevent tritium from escaping into the room should a leak develop in the glovebox. However, outward permeation of HTO through the gloves and inward permeation of room moisture are not affected by the pressure inside the glovebox.

Temporary Enclosures

At times, maintenance or repair work is done on equipment that cannot be moved into a glovebox or fume hood and that has a high potential to release tritium. For these activities a temporary box ("tent"), may be constructed over the equipment, and an existing cleanup system installed to process the air. Alternatively, if the tritium at risk is not significant, the enclosing atmosphere may be purged to the stack. If the enclosure is small, gloves and glove ports may be fitted to the side of the enclosure. For larger enclosures entry may be required. In such cases, personnel should work in air-supplied suits inside the enclosure.

Protection by Local Ventilation

In spite of the greater protection afforded by gloveboxes, fume hoods are commonly used at tritium facilities for handling or storing material with low quantities of tritium or with low-level contamination. Limits are generally imposed on the quantities used or stored in these hoods.

Fume hoods are also used to protect personnel at the outside door of glove-box pass boxes where materials are passed into and out of the boxes. Ideally, any tritium released in a hood from outgassing or a leaky container, for instance, is routed to the hood's exhaust duct. However, turbulence may occur at the hood entrance, resulting in backwash and possible contamination of personnel if the face velocity is not adequate for the design of the hood, the activities in the hood, or the local conditions (such as traffic in front of the hood). No hood should be used that has not been thoroughly surveyed and judged acceptable for tritium use.

For small operations local ventilation is commonly provided at the work site through a flexible ventilation duct ("elephant trunk") directed to the room exhaust system. The exhaust of these ducts is generally directed to the building ventilation exhaust system, which of itself may be adequate to supply the needed air flow for the duct without help from an additional in-line blower.

Flexible ducts can provide adequate ventilation during maintenance in a glovebox with a panel removed. In this application, a flexible duct can be connected to a gloveport before the panel is removed, and then the work can proceed safely.

Supplied-Air Respirators

In general, only supplied-air respirators are effective in preventing inhalation of airborne tritium. Two types of air-supplied respirators are available: self-contained breathing apparatus (SCBA) and full-face supplied air masks.

An SCBA, consisting of a full-face mask fed by a bottle of compressed air carried on the worker's back, provides excellent protection against HTO inhalation. Because the mask provides no protection against absorption by most of the skin, the SCBA is normally reserved for emergency use only. The protection factor of 3 or more afforded by the SCBA may be adequate for some applications. An SCBA can be used as an added precaution during certain maintenance or operations that experience has shown should not result in the release of significant amounts of HTO. Nevertheless, the potential for exposure is real, and the SCBA gives the worker time to leave the area if necessary before a skin exposure occurs.

Full-face supplied-air masks are also available. Because the air is normally supplied by a fixed-breathing-air system, they are not practical for many emergency situations and, consequently, are not as popular as SCBAs.

Supplied-Air Suits

Because of the inherent disadvantages associated with respirators and other breathing apparatus, supplied-air plastic suits that completely enclose the body are often used by facilities that handle large quantities of tritium. Although they afford reasonably complete body protection, they are slow to don and cumbersome to wear. For these reasons, they are not favored for rescue work where time and mobility are important considerations. For certain maintenance operations outside of gloveboxes with a high degree of risk, supplied-air suits may be quite useful.

For tritium work, supplied-air suits are constructed of materials that have acceptable permeation protection against HTO and provide good tear and abrasion resistance. Because of the closed environment, and the additional background noise caused by the flow of air into the suits, communication between personnel may require special equipment or methods.

Protection from Surface Contamination

Experience at tritium laboratories has shown that many tritium exposures to personnel occur as a result of contact with highly contaminated surfaces. Sudden and significant releases of airborne tritium occur mostly as the less toxic form HT and are quickly detected by portable or strategically placed, fixed tritium monitors. The result is that the exposure and uptake of airborne tritium are minimized. (Heavy-water reactors, of course, present a more significant risk of exposure to tritiated water vapor than to tritium gas.) The presence and degree of contamination may be unknown until measurements are made. Consequently, the importance of routine and special monitoring surveys for surfaces that personnel might contact cannot be overestimated.

Protective clothing worn by workers is one of the most important aspects of an effective health physics program. Because tritium can be absorbed easily through the skin or by inhalation, personnel protective equipment has to protect against both exposure routes. The following paragraphs describe protective measures and equipment.

Protective Clothing

Lab Coats and Coveralls

Lab coats and coveralls (fabric barriers) are worn in most tritium facilities. Lab coats are routinely worn to protect personal clothing. Coveralls are sometimes worn for added protection instead of a lab coat when the work is unusually dusty, dirty, or greasy. The protection afforded by lab coats and coveralls is minimal (except for short exposures) when tritium is airborne, but they are more effective in preventing skin contact with contaminated surfaces.

Disposable waterproof and water-resistant lab coats and coveralls have been tested at various laboratories. They are not popular for everyday use because of the cost and excessive discomfort inflicted on the worker. Most facilities prefer using ordinary open-weave fabrics for lab coats and coveralls and using an approved laundry for contaminated clothing. Some facilities have chosen to use disposable paper lab coats and coveralls, exchanging the costs associated with a laundry for the costs associated with replacement and waste disposal.

Shoe Covers

Although shoe covers provide protection against the spread of contamination and exposure, the routine use of shoe covers in a tritium facility is usually weighed against actual need. Shoe covers can offer both a degree of personnel protection and control over the spread of contamination on floors. However, in modern facilities where tritium is largely controlled by the use of secondary containment, shoe covers may not be required. Such facilities can easily maintain a clean laboratory environment by the use of regular smear surveys and good housekeeping. Using liquid-proof shoe covers until spills are cleaned up should be considered following spills of tritium-contaminated liquids and solids to prevent the spread of local contamination.

Gloves

In most operations, the hands and forearms of workers are vulnerable to contact with tritium surface contamination. The proper use and selection of gloves are essential. Many factors should be considered in selecting the proper type of glove. These include chemical compatibility, permeation resistance, abrasion resistance, solvent resistance, glove thickness, glove toughness, glove color, shelf life, and unit cost. Gloves are commercially available in butyl rubber, neoprene, polyvinyl chloride (PVC) plastics, latex, etc.

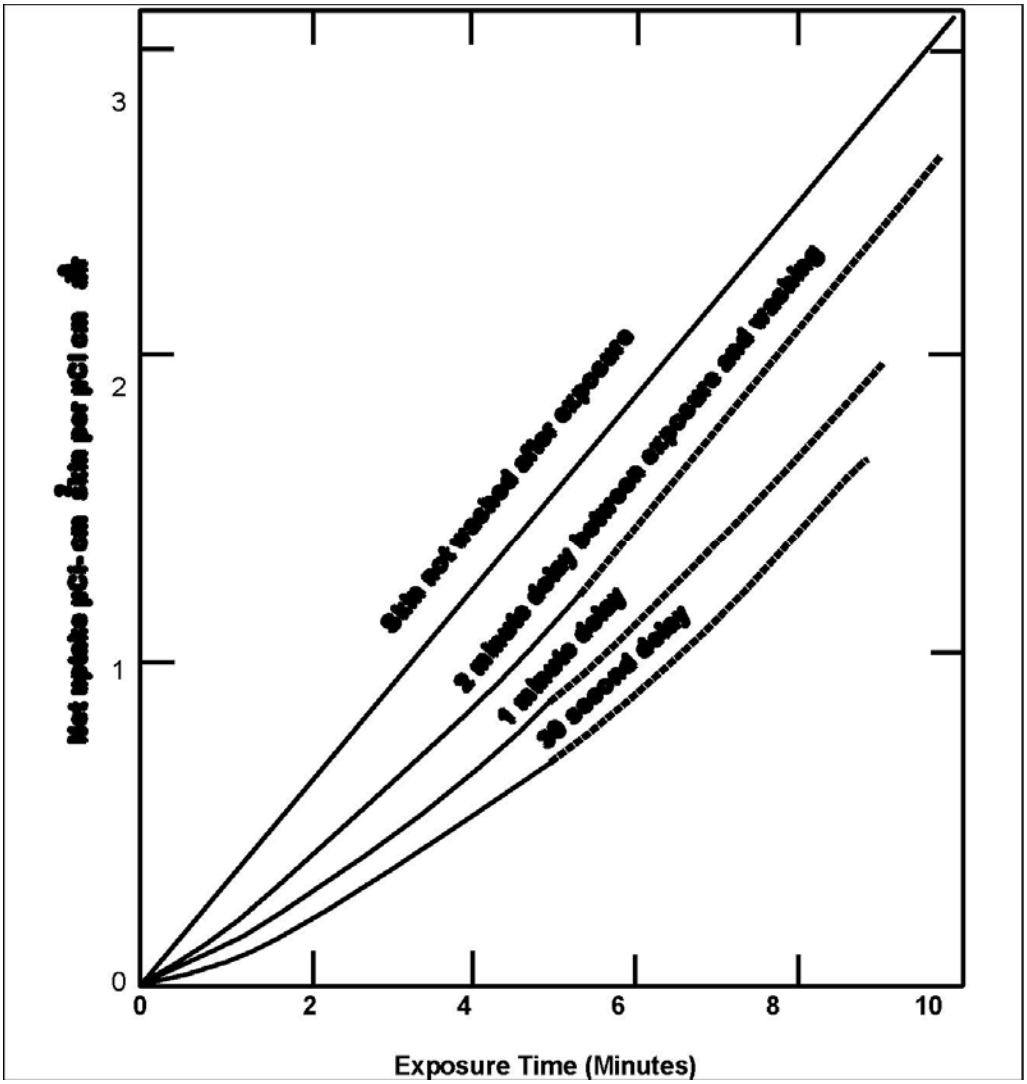
The most common gloves found in tritium laboratories are the light-weight, disposable short glove (usually PVC or latex) used for handling lightly contaminated equipment. Depending on the level of contamination, such gloves may be changed frequently (every 10–20 minutes), a second pair may be worn, or heavier gloves may be used instead. When using gloves for this purpose, the work should be planned so that contaminated gloves doe not spread contamination to surfaces that are being kept free of contamination.

When working in a glovebox using the box gloves, disposable gloves are worn to prevent uptake of HTO contaminating the outside of the box gloves. Again, depending on the level of contamination, more than one additional pair may be required, one of which may be a longer, surgeon's length, glove.

In spite of all the precautions normally taken, workers may occasionally be contaminated with tritium. The skin should be decontaminated as soon as possible after any potential skin exposure to minimize absorption into the body. Effective personal decontamination methods include rinsing the affected part of the body with cool water and soap. If the entire body is affected, the worker should shower with soap and water that is as cool as can be tolerated. Cool water keeps the pores of the skin closed and reduces the transfer of HTO across the skin. The importance of washing the affected skin as soon as possible after contamination cannot be overemphasized. Figure G-8[107] illustrates the effect of speed on reducing the uptake and the resultant dose. Even if gloves are worn when handling contaminated equipment or when working in contaminated glovebox gloves, it is good practice to wash the hands after removing the gloves.

[107]W. R. Bush, *Assessing and Controlling the Hazard from Tritiated Water*, AECL-4150, Atomic Energy of Canada LTD., Chalk River, Ontario, 1972

Figure G-18: Reducing HTO Uptake



This figure shows reduction in HTO uptake by washing after exposure to HTO vapor.

EMERGENCY RESPONSE

It is important to examine the history of accidents that have occurred in tritium facilities and to consider foreseeable unplanned events in order to minimize or mitigate their effects or to prevent their taking place at all. When an accident does occur, requirements for reporting accidents should be followed.

Facilities that handle significant quantities of radioactive material have to have a site-specific emergency plan. All radiological workers at the site should be familiar with certain aspects of this plan. In addition, job assignments involving radiological hazards are typically covered by procedures and work permits that include steps for emergency situations that may arise during the course of the work. Radiological workers should be familiar with these procedures or be accompanied by a radiological control technician (RCT) to provide guidance in case of an emergency.

Emergency Steps to Take

The initial steps to be undertaken following a serious accident should include the following:

- Warning others in the vicinity
- Evacuating the laboratory if an airborne release has occurred
- Requesting any necessary assistance
- Giving urgent first aid in the event of serious injuries (This should take priority over problems that arise from contamination)
- Starting personnel decontamination procedures
- Submitting urine samples following the schedule outlined for nonroutine samples.

Decontamination of Personnel

Personnel should be decontaminated by the following procedures:

- Remove clothing thought to be contaminated
- Wash hands with soap and cool water
- Wash other parts of the body (such as face, hair, and arms) that may have been exposed to tritium, or immediately shower with cool water and soap
- If mouth-to-mouth resuscitation is to be given to a contaminated victim, the victim's mouth should first be wiped with a damp cloth.

Decontamination of Surfaces

Following a tritium spill involving a liquid with high specific activity, the area may have to be isolated and other protective measures taken before cleaning up the liquid. Monitoring for possible airborne tritium must be started to determine the need for respiratory protection or skin protection. After the spill has

been cleaned up, residual contamination will remain. Depending on the level of contamination, any further steps needed to prevent the spread of contamination and reduce the level to an acceptable value should be determined.

Following a release of tritium gas, surfaces would not be expected to be heavily contaminated. If tritiated water vapor is released, the contamination may be greater, depending on the amount and activity of the released vapor. In any case, smear and air surveys will be used to determine the course of action needed to control and reduce the contamination safely.

Operational Emergencies

This Primer is provided as an information resource only, and is not intended to replace any radiation worker or hazardous materials training. The Primer presents the theoretical concepts and good practices that form the basis of safe tritium handling.

Facilities that handle significant quantities of radioactive material must have a site-specific emergency plan and implementing procedures. The plan and procedures are required by DOE O 151.1C and implementing guidance on the topics of recognition, categorization/ classification; protective actions; notification; consequence assessment; etc., can be found in the DOE G 151.1-series, particularly DOE G 151.1-4. All radiological workers at the site should be familiar with certain aspects of this plan, the Order, and the Guides.