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Author's notes

Over my career in health physics starting with a US Army CBR unit at Dugway Proving Grounds in 1965 I have needed to quickly find that elusive data point that I just couldn't remember, even though I knew the information was in one of my several hundred reference books.

So, here it is today, the product of my work to assemble useful field information from a wide range of sources.

I must give credit to those individuals who put their efforts into creating the original data. Without their work, this document could not have been assembled.

My family has given me their unlimited support in my development of this reference book and in my projects all through my career. Sandy my wife of 40 years and our two daughters Susan and Sarah and their excellent husbands, Bill Gilson and Ian Curtis, our son-in-laws, continue to provide me with a steady foundation that allows me to try out new concepts.

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I TYPES OF SAMPLES

Particulates

Air sampling for particulates includes both solid and liquid aerosols. The particulates may be radioactive, toxic, nuisance, or a combination of these characteristics. It is important to know the particle size distribution of the aerosols. Further the density of the particles must be taken into account.

Gases

Air sampling for gases may be for radioactive, toxic, nuisance, or oxygen deficiencent atmospheres or a combination of these characteristics. The gases sampled are single molecules but may be heavier than air.

Special Cases

Air sampling may involve both particulates and gases in the same sample.

There are radioactive isotopes that are gases but have particulate progeny. Those progeny initially exist as single molecules but will quickly agglomorate onto dust particles in the air, then they react as true particulates for air sampling purposes. However, before those particulate progeny do agglomorate onto dust particles they will react more like gas molecules which will affect the sampling technique required.

Vapors of metals or organics may change to particles as they cool or as they react with the atmosphere.

II SAMPLE COLLECTION AND ANALYSIS METHODS

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I. Affect of Sample Inlets on Collection

A. Passive and Diffusion

Passive and diffusion sampling of air requires the substance being sampled to come into contact (or near contact) with the container, collection media, or detection assembly.

Examples of this sampling method are; smoke, CO, and CO_2 monitors where the substance in the air (in this case the smoke or CO or CO_2) migrate throughout the space where the detectors are located and when the substance enter into the active volume of the detector an alarm is generated.

Another example is the Electret for sampling radon and thoron. A charged disc is placed inside a container which has an opening through which air can migrate. The radon and thoron in the air will ionize the air inside this container due to the radioactive decay of these gases and their progeny. The ionization of the air then causes the charged disc to lose part of its charge. When the Electret is collected later the remaining charge on the disc is determined and the amount of charge lost is related to the radon and thoron concentration of the air the Electret was exposed to.

Colorimetric detectors are also used in a passive mode for the detection of toxic airborne substances. A color change or color intensity change indicates the detector has reacted to the toxic substance. The substances detected by this method are gases such as chlorine and ammonia and for military and homeland security applications colorimetric detectors for biological and chemical weapons are used.

B. Flow Through

Flow through chambers generally are combined with some detection method. Applications include sampling for radioactive substances, both gas and particulate, and sampling for toxic substances.

When sampling for radioactive substances the typical flow through chamber is a version of the air ionization chamber used for the detection of gamma detection. The actual gamma radiation background must be subtracted from the total signal level to determine the actual concentration of the radioactive substance.

Sampling for toxic substances using a flow through chamber generally requires an electrochemical detection method. Some flow through detectors for toxic substances have the capability of detecting more than one type of toxic substance.

Sampling for oxygen deficient atmospheres is another application for flow through chambers.

C. Grab

The basic technique in grab sampling is to cause the air to be sampled to flow through or into the collection container.

This can be accomplished by using a pump and when the container is sufficiently purged simply close the outlet and inlet valves on the container.

Another technique used is to fill the sampling container with water and when the inlet and outlet valves are opened the water flowing out draws the air to be sampled into the container.

Sampling containers can be evacuated using a vacuum pump before sampling the air and when the sample needs to be collected the technician simply opens the inlet valve on the sampling container.

D. Filtration

Filtration is the most widely used method for collecting samples of aerosols.

The methods and equipment range from high volume samplers (up to about 40 cfm) for environmental or short-term workplace sampling, to low-volume lapel samplers (1 lpm or less) for collecting aerosols in the breathing zone of individual workers.

Low-pressure-drop, cellulose filters are commonly used, and samples can be easily reduced to ash or dissolved for analysis without the filter material interferring with the analysis.

Concerns for penetration of particles into the filter matrix are a function of the type of filter and the filter analysis method. Membrane filters with their superior front-surface collecting characteristics are preferred over fiber-type filters when alpha particle spectroscopy is applied. Shielding by the filter media is seldom a concern for detection of gamma radiation.

Filter Media Characteristics for Alpha CAMs

Filter Type	Pore Size	Filter ΔP	FWHM keV
Millipore			
Fluoropore	5 um	0.5"Hg	370
Fluoropore	3 um	0.8"Hg	300
SMWP	5 um	2.0"Hg	450
SSWP	3 um	3.1"Hg	350
AW19	1.2 um	3.8"Hg	450
Durapore	5 um	4.3"Hg	490
AP40	0.7 um	2.6"Hg	490
Bladewerx			
Speclon 1.5	1.5 um	2.6"Hg	300
Speclon 5.0	5 um	0.4"Hg	370
Whatman			
GFA	0.3 um	2.8"Hg	490
EPM 2000	0.6 um	1.8"Hg	1,000
Gelman			
A/E Glass	1.0 um	2.3"Hg	1,000
Versapor 3000	3.0 um	2.3"Hg	450
Hollingsworth & Vose			
HV LB5211	0.3 um	1.0"Hg	650

The rated pore size is for >99.99% collection efficiency for that size particle and greater. All of these filters have >99% collection efficiency for particles as small as 0.3 um. The stated pressure drop is for a 40 mm collection diameter with an air flow rate of 2 ACFM and barometric pressure of 23.1"Hg. The FWHM is for Po-214 at 7.68 MeV and was determined using a 25 mm collection diameter and a 25 mm diameter diffused junction detector with a spacing of 4 mm. The pressure drop will be higher and the FWHM will be broader at higher barometric pressures.

E. Absorption and Adsorption

Absorption and adsorption are both used in air sampling and are sometimes hard to distinguish from each other.

Absorption is a process in which atoms, molecules, or ions enter some bulk phase - a gas, liquid, or solid material.

Adsorption is a process in which a gas or liquid aerosol accumulates on the surface of a solid or liquid, forming a film of molecules or atoms.

Sorption refers to both absorption and adsorption while desorption is the reverse of either process.

Anhydrous calcium sulfate is an example of absorption where water vapor (or tritium oxide) is collected by passing an air stream through a cartridge containing the anhydrous calcium sulfate. The moisture content of air can then be measured by gravimetric or other methods and tritium oxide in the air can be measured directly or indirectly using either a radiation detector or liquid scintillation counting.

Silica gel, zeolites, and activated charcoal are examples of adsorption where toxic or radioactive substances are collected by passing an air stream through a cartridge containing one of these materials. The radioactive substances collected by these materials can be measured directly or indirectly using radiation detectors. Toxic substances collected by these materials are typically extracted from the materials before they are measured.

F. Bubblers

Bubblers consist of an air pump and a liquid container which has an inlet tube going to near the bottom of the bubbler. The air pump pulls air to be sampled into the inlet tube and the air goes through the tube to the bottom of the liquid container where the air “bubbles” into the liquid and rises to the top of the liquid container where the air is drawn off by the air pump. Water is the typical liquid used but other liquids may be used depending on what substance is desired to be collected.

Bubblers are used to collect both gases and aerosols and these may be radioactive or toxic gases and aerosols.

In some cases real-time analysis of the substances being collected are possible by using chemicals in the liquid which will react with the substances being collected.

The substance collected in the liquid may be analyzed at some later time also.

An example of a bubbler sample collection technique is the elemental tritium and tritium oxide bubbler. Elemental tritium is used in several applications and must be adequately monitored for in order to apply safety controls. Elemental tritium is not as hazardous as tritium oxide but elemental tritium quickly converts to the oxide form upon exposure to the atmosphere. Typically the air being sampled is drawn through a series of collection vials with an appropriate liquid in them and the tritium oxide is effectively collected in those vials but the elemental tritium passes through them.

The air stream is then directed to a catalyst and heater section where the elemental tritium is converted into tritium oxide. From there the tritium oxide (which was elemental tritium just before) is drawn through another set of collection vials identical to the first set. The first set of vials contains the tritium oxide from the original sample while the second set of vials contains the elemental tritium which was converted to the oxide form. When the contents of the vials are analyzed a measurement of elemental tritium and tritium oxide can be derived.

G. Impactors

Impactors are used to collect aerosols, either solid or liquid particles.

An air pump pulls air through a opening small enough to increase the velocity of the air stream to a level such that large particles in the air cannot deviate from their straight flight and therefore “impact” on a plate. Smaller particles can go around the impactor plate because they have less kinetic energy than the larger particles. Multiple impactor plates in series and with higher and higher air velocities separate the particles in distinct size ranges.

The cascade impactor and the Andersen sampler are examples of impactor particle collection techniques.

H. Particle Separators

Cyclone separators use a method similar to impactors in that the larger particles cannot follow the main air stream at some velocities. The large particles then drop out the bottom of the cyclone separator while the air stream with much smaller particles go out the top of the cyclone separator.

Just as with multi-stage impactors, multi-stage cyclone separators can be used to collect a range of particle sizes.

I. Affect of Sample Inlets on Collection

The design of the sample inlet is critical to the efficacy of the collection system.

The use of non-conductive materials should be avoided for the collection of aerosol particles due to electrostatic collection of those particles on the sample inlet before they get to the point of collection.

The use of non-reactive materials should always be used regardless of whether sampling for gases or aerosols.

The length, inside diameter, and bends in the sample inlet should be sized so as to minimize loss of any of the sample in the sample inlet itself.

Calculations should be performed on transport velocities to ensure that the collection of aerosols remains isokinetic throughout the sampling system.

III AIR SAMPLE PUMPS

INTRODUCTION

Equipment used to generate vacuum is similar to air compressors. It's even possible to generate compressed air or vacuum with the same machine, depending on how it is installed. Vacuum pumps generally can be considered as compressors in which the discharge rather than the intake is at atmospheric pressure. The vacuum in a chamber is created by physically removing air molecules and exhausting them from the system. Removing air from the enclosed system progressively decreases air density within the confined space, thus causing the absolute pressure of the remaining gas to drop and a vacuum is created. Because the absolute maximum pressure difference that can be produced is equal to atmospheric pressure (nominally 29.92"Hg at sea level), it is important to know this value at the work site.

For example, a pump with a maximum vacuum capability of 24"Hg cannot generate a 24" vacuum when the atmospheric pressure is 22" Hg (as in Mexico City, for instance). The proportion of the air evacuated will be the same, however. This pump therefore will pull
22 x 24/29.92 = 17.6"Hg vacuum in Mexico City.

- The maximum pressure difference produced by pump action can never be higher than 29.92"Hg (14.7 psi), since this represents a perfect vacuum.
- The mass of air drawn into the pump on each suction stroke, and hence the absolute pressure change, decreases as the vacuum level increases.
- At high vacuum levels, there is significantly less air passing through the pump. Therefore, virtually all the heat generated by pump operation will have to be absorbed and dissipated by the pump structure itself.

Positive Displacement Vacuum Pumps

Vacuum pumps fall into the same categories as air compressors do. Tthey are either positive displacement or non-positive displacement machines. A positive displacement pump draws a relatively constant volume of air despite variations in the vacuum levels. The principle types of positive displacement vacuum pumps are the piston, diaphragm, rocking piston, rotary vane, lobed rotor, and rotary screw designs.

Reciprocating Piston Pumps -The primary advantage of the piston design is that it can generate relatively high vacuums from 27 to 28.5"Hg and do so continuously under all kinds of operating conditions. The major disadvantages are somewhat limited capacities and high noise levels, accompanied by vibrations that may be transmitted to the base structure. In general, the reciprocating piston design is best suited to pulling relatively small volumes of air through a high vacuum range.

Diaphragm Pumps -The diaphragm unit creates vacuum by flexing of a diaphragm inside a closed chamber. Small diaphragm pumps are built in both one- and two-stage versions. The single stage design provides vacuums up to 24"Hg, while the two stage unit is rated for 29"Hg.

Rocking Piston Pumps -This design combines the light weight and compact size of the diaphragm unit with the vacuum capabilities of reciprocating piston units. Vacuums to 27.5"Hg are available with a single stage; two-stage units can provide vacuums to 29"Hg.

Rotary Vane Pumps -Most rotary vane pumps have lower vacuum ratings than can be obtained with the piston design: only 20 to 28"Hg maximum. However, some two stage oil-lubricated designs have vacuum capabilities up to 29.5"Hg. The rotary vane design offers significant advantages: compactness; larger flow capacities for a given size; lower cost (about 50 percent less for a given displacement and vacuum level); lower starting and running torques; and quiet, smooth, vibration free, continuous air evacuation without a receiver tank.

Rotary Screw and Lobed Rotor Pumps - Vacuum capabilities of rotary screw pumps are similar to those of piston pumps, but evacuation is nearly pulse-free. Lobed rotor vacuum pumps, like the corresponding compressors, bridge the gap between positive and non-positive displacement units. Air flow is high but vacuum capabilities are limited to about 15"Hg. Capabilities can be improved with staging.

Non-positive Displacement Vacuum Pumps

Non-positive displacement vacuum pumps use changes in kinetic energy to remove air from a system. The most significant advantage of this design is its ability to provide very high volume flow rates, much higher than possible with any of the positive displacement designs. But because of their inherent leakage, these machines may not be practical for applications requiring higher vacuum levels and low flow rates. The principle types of non-positive displacement vacuum pumps are the **centrifugal, axial-flow, and regenerative** designs. Single-stage regenerative blowers can provide vacuums up to 7"Hg with flows to several hundred cfm. Vacuum capabilities of these designs are improved when they are multi-stage.

Evaluating Vacuum Pump Performance
The primary performance criteria cover three characteristics:
- Vacuum level that can be produced.
- Rate of air removal.
- Power required.

Somewhat less critical are temperature effects and certain other characteristics. In general, the best pump for a specific job is the one having the greatest pumping capacity at the required vacuum level and operating within an acceptable horsepower range.

Vacuum Level - A pump's vacuum rating is the maximum vacuum level for which it is recommended. The rating is expressed in “Hg and is specified for either continuous or intermittent duty cycles.
Most vacuum pumps can't come near the theoretical maximum vacuum (29.92"Hg at sea level) because of internal leakage. For a reciprocating piston pump the upper vacuum limit may be 28 or 28.5"Hg, roughly 93 to 95 % of the maximum theoretical value. Internal leakage and clearance volume establish the highest vacuum a pump can produce. For some pumps, this is also the vacuum rating. In other types, however, heat dissipation is a problem. For these, the maximum vacuum rating might be based on allowable temperature rise. For example, good wear life for some rotary vane pumps requires a maximum 180 F (82 C) rise in casing temperature at the exhaust port. Vacuum ratings will be based on this temperature rise. The vacuum rating listed for a pump is based on operation at 29.92"Hg.

Operating where atmospheric pressure is lower will reduce the vacuum the pump can produce. An adjusted vacuum rating for such locations can be determined by multiplying actual atmospheric pressure by the ratio of the nominal vacuum rating to standard atmospheric pressure:

$$\text{Adjusted Vacuum Rating} = \text{Actual Atomospheric Press} \times \frac{\text{Nominal Vacuum Rating}}{\text{Standard Atmospheric Press}}$$

Air Removal Rate -Vacuum pumps are rated according to their open capacity, which is the volume of air (expressed in cfm) exhausted when there is no vacuum or pressure load on the pump. Effectiveness of the vacuum pump in removing air from the closed system is given by its volumetric efficiency, a measure of how close the pump comes to delivering its calculated volume of air.

This equation is applied in two different ways:

- **True (or Intake) Volumetric Efficiency** -The volume of air removed during a given time period is converted to an equivalent volume at the temperature and absolute pressure existing at the intake.
- **Atmospheric Volumetric Efficiency** -The volume of air removed by the pump is converted to an equivalent volume at standard conditions (14.7 psi and 68 F).

The displacement is the total volume swept by the repetitive movement of the pumping element during the same time period (usually one revolution). With various vacuum pumps having the same displacement, it is the difference in volumetric efficiencies that accounts for the difference in free air capacities.

Since these differences exist, pump selection should be based on actual free air capacity rather than on displacement. In short, the air removal rate is a measure of vacuum pump capacity and the capacity of standard machines must be determined from the manufacturers' tables or curves showing cfm of free air delivered at rated speed for vacuum levels ranging from 0 “Hg (open capacity) to the maximum vacuum rating. Free air capacity at different speeds for a given vacuum also may be included in the manufacturers' performance curves. The rated capacity of any pump is highest at 0 “Hg and will drop rapidly as the vacuum level increases. This reflects a drop in both volumetric efficiency and the volume of air that can be drawn into the pumping chamber. To repeat, a basic characteristic of positive displacement pumps is that capacity drops as the vacuum level increases. The same principle holds for diaphragm pumps.

Effects of Temperature Rise

Vacuum pump performance is significantly affected by heating of the pump itself. At higher vacuum levels, there is very little air flow through the pump. There is thus very little transfer of internal heat to this remaining air. Much of the heat generated by friction must be absorbed and dissipated by the pump casing. Since some pumps generate heat faster than it can be dissipated, a gradual rise in pump temperature results, drastically reducing service life. One solution is to give careful consideration to pump ratings. For example, a continuous-duty pump should have a high maximum vacuum rating.

Summary of Vacuum Pump Selection Factors

These basic questions should be answered before deciding which vacuum pump is best suited for a particular application:

- What degree of vacuum is required?
- What flow capacity (cfm) is required?
- What horsepower and speed requirements are needed to meet vacuum level and capacity values?
- What power is available?
- Will duty cycle be continuous or intermittent?
- What is the atmospheric pressure at the work site?
- What is the ambient temperature?
- Are there any space limitations?

Vacuum Ratings and Typical Pump Capacities

Max. Vacuum Rating ("Hg)	CFM Range	
27.5 to 28.5	1 to 1,000	Piston (multistage)
25.5 to 29	0.1 to 2	Rocking piston
24 to 29	0.1 to 8	Diaphragm (single & multistage)
10 to 28	0.5 to 50	Rotary vane
14 to 22	5 to 2,000	Multi-stage Centrifugal
14 to 22	5 to 200	Multi-stage Regenerative
5 to 7	5 to 200	Single-stage Regenerative
1 to 2	1 to 10,000	Single-stage Centrifugal

Nomenclature

V_{vc} = volume of expanded air, cu ft
V = volume of free air, cu ft
P = pressure (psi)
Pa = absolute pressure (psia)
P1 = inlet (or original) absolute pressure
P2 = discharge (or final) absolute pressure
V1 = inlet (or original) volume
V2 = discharge (or final) volume
T1 = inlet (or original) absolute temperature
T2 = discharge (or final) absolute temperature
m = mass
T = absolute temperature Kelvin
R = 0.08207 lit-atm per mole-K

Gas Law Units

Positive Gauge Pressure is the pressure above atmospheric pressure (measured in psig).

Negative Gauge Pressure (vacuum) is the difference between atmospheric pressure and the pressure remaining in the evacuated system (measured in "Hg or negative psig).

Absolute Pressure is the pressure above a perfect vacuum condition measured in psia. When using gas laws, pressure must be absolute pressure values.

Metric Units -in metric systems pressures are given in "bars" equal to 14.50 psi. The unit of force is the newton, and the unit of area is the square meter. One bar is 10,000 newtons per square meter.

Temperatures Used in Gas Laws

Absolute Temperature is the temperature above absolute zero, the point where all thermal activity ceases. Such a perfect gas would exert no pressure if kept at a constant volume. In SI units, absolute zero is - 273 C, and absolute temperatures are given in degrees Kelvin (K).

Volume Measurements for Gas Laws

For the General Gas Law, the volume unit must correspond to the value of R used. For example, when the value 53.3 is used, volume must be in cubic feet. For other laws, the only requirement is that all volumes be given in the same units.

Gas Laws

The relationships of pressure, volume, and temperature of a quantity of air are interrelated. The first three laws cover conditions where the quantity or mass of air is constant. The fourth law (General Law) provides for computation involving change in the mass of air.

Boyle's Law - $P1V1 = P2V2$

This basic law covers the relationship between changes in pressure and volume when temperature remains constant.

Charles' Law - $P1/P2 = T1/T2$: $V1/V2 = T1/T2$

The basic forms above cover changes in pressure and volume caused by temperature changes. A pressure change is calculated for a system where the volume is constant. A volume change is calculated where the pressure remains constant.

Combined Gas Law
P1V1/T1 = P2V2/T2

General Gas Law or Equation of State of an Ideal Gas
mR= PV/T
The above basic form includes the effect of mass (in pounds). The right-hand portion of the equation is the same as the Combined Gas Law. R is a constant that varies with the gas being considered and the units used. For air in units of the U.S. system (T in degrees Rankine, V in cubic feet, m in pounds mass, and P in pounds per square foot absolute-to obtain psfa, multiply psia by 144), R has the value 53.3.

Variation: PV = nRT
In this variation, n represents the amount of gas in moles. A mole is 6.02E+21 molecules; its weight in grams equals the molecular weight of the gas. This makes R independent of the gas involved. In metric units (T in degrees Kelvin, V in liters, and P in atmospheres), R has the value 0.08207.

Flow Measurements - The volume of air delivered by a compressor or removed by a vacuum pump is given in cubic feet per minute (cfm). This may be either cfm at actual temperature and pressure or standard cubic feet of air per minute (scfm)-that is, cfm at atmospheric pressure and a standard temperature of 68 F (20 C). For utmost accuracy, scfm also requires correction to a standard humidity of 36 percent.) The term "free air" is often used interchangeably with "standard air." Strictly speaking, "free air" refers to air at ambient conditions - the conditions at a compressor's intake or a vacuum pump's discharge port.

Power - The units of power are horsepower (hp) and watts (w) or kilowatts (kw). One U.S. horsepower equals 0.746 kw and 1.014 metric horsepower.

Absolute Pressure - In pressure or vacuum systems, absolute pressure is the pressure above a perfect vacuum condition (zero pressure). In a pressure system, it is equal to the positive gauge pressure plus atmospheric pressure. In a vacuum system, it is equal to the negative gauge pressure subtracted from atmospheric pressure. U.S. units for absolute pressure are pounds per square inch, absolute (psia).

Adiabatic - A change, such as expansion or compression, without loss or gain of heat. Any sufficiently fast process is approximately adiabatic.

Atmosphere - Unit of pressure that will support a column of mercury 29.92 inches high at 0 C, sea-level, and latitude 45. Actual day-to-day atmospheric pressure fluctuates about this value.

Atmospheric Pressure - Pressure exerted by the atmosphere in all directions, equal at sea level to about 14.7 psi.

Back Pressure - Resistance to flow in a system.

Barometer - Device for measuring atmospheric pressure at a specific location.

Barometric Pressure - The reading, in inches of mercury ("Hg), showing atmospheric pressure at a given location.

Differential Pressure - Difference in pressure between two points in a system or component.

Displacement - The total volume swept by the repetitive motion of the pumping element. Displacement per revolution is determined by size of the pumping chamber(s). Displacement per minute also depends on compressor speed. Displacement is meaningful only in positive displacement compressors.

Efficiency, Volumetric - Ratio of actual capacity to theoretical displacement multiplied by 100 percent.

Free Air - Air under the atmospheric conditions (including temperature) at any specific location.

Gauge Pressure (Positive) - The pressure differential above atmospheric pressure (see pressure gauge).

Gauge Pressure (Negative) - The difference between pressure remaining in an evacuated system and atmospheric pressure (see vacuum gauge). Also known as -gauge vacuum" or "vacuum level." In effect, it is the pressure drop produced by evacuating the system. Measured in inches of mercury ("Hg). Caution: It is a potentially misleading term which must be carefully defined when used; negative pressure (absolute) doesn't exist.

Maximum Vacuum Rating - Highest vacuum level recommended for a vacuum pump.

Non-positive Displacement - (Of a compressor or vacuum pump). One that uses kinetic energy to create pressure gradients (slopes) for moving air. This applies to Regenerative, Axial flow, and Centrifugal pumps.

Open Capacity - The volume of air exhausted per minute when there is no vacuum or pressure load on the pump, expressed in cfm.

PSIG - Pounds per square inch gauge-pressure above or below (vacuum) atmospheric pressure.

Positive Displacement - (Of a compressor or vacuum pump.) One that moves a specific volume of air for each cycle of operation.

Pressure Differential - Difference in pressure between two points in a system or component.

Pressure Drop - Any reduction in pressure from normal value.

Pressure Gauge - A device that displays the pressure level in a system. Most gauges use atmospheric pressure as a reference level and measure the difference between the actual pressure and atmospheric pressure; the readout is called "gauge pressure." (A gauge that reads below atmospheric is called a vacuum gauge).

Rated Capacity (Vacuum) - The cfm of free air exhausted by a vacuum pump at rated speed. Usually given for vacuums ranging from 0 “Hg to the maximum vacuum rating.

Vacuum Receiver Tank - Container in which gas is stored under vacuum as a source of pneumatic fluid power. Accommodates sudden or unusually high system demands. Prevents frequent on/off cycling of an air compressor or vacuum pump and absorbs pulsations.

Regulator - Device to control flow of gases, thus controlling the magnitude of the force and torque produced by the actuator.

Standard Air - Air at a temperature of 68 F, a pressure of 14.70 psia, and a relative humidity of 36 percent.

Vacuum - A space containing air or other gas at less than atmospheric pressure; usually expressed in "Hg.

Vacuum Gauge - Device for determining the pressure level in a partial vacuum.

Vacuum Pump - A device that pulls air out of a closed container or system.

Vacuum Relief Valve - A valve that controls system vacuum level. It operates by providing a modulated flow of atmospheric air into the system.

Volumetric Efficiency - The ratio of a pump's actual delivery to its computed fluid delivery multiplied by 100 percent.

The author expresses gratitude to the Gast Manufacturing Corporation who provided much of the information in this section.

IV AIR SAMPLE PUMP POWER SOURCES

A. AC Powerline

B. Battery

C. Generator

D. Solar Power

E. Wind Power

A. AC Powerline

This section applies to those portable or temporary AC powerline operated vacuum pumps. Permanently installed systems must conform to building codes.

Use the following table and equations as guidance in determining electrical wiring requirements for your system.

AWG gauge	Ohms per 100 feet of wire	Maximum Amps
2	0.016	94
4	0.025	60
6	0.040	37
8	0.063	24
10	0.1	15
12	0.16	9.3
14	0.25	5.9
16	0.4	3.7

Determine what size of electric motor you need for your vacuum system. You can refer to the vacuum pump manufacturers data sheets after you determine your vacuum and air flow rate requirements to determine the power requirements.

If the manufacturer states the electric motor rating in horsepower convert that to watts by multiplying # Horsepower by 746 watts per horsepower to calculate the watts required.

Example: A 5 horsepower pump needs 5 x 746 = 3,730 watts of electric power. If you use single phase 120 VAC power use this equation to determine your motor’s running current.

Amps = Watts / Volts

Amps = 3730 / 120 = 31 amps

Use Ohm's Law to determine if your powerline is causing an unacceptable voltage drop on your system.

V = Volts	V = I x R
I = Amps	I = V / R
R = Ohms	R = V / I

Example: If you use a 400 foot length of 16 gauge powerline to operate a vacuum pump that uses 3.7 amps calculate the voltage loss using this equation; V = I x R

V = 3.7 x 0.4 x 4 = 5.92 Volts less than the standard 120 VAC at the source.

This causes your vacuum pump to operate with lower efficiency and greater heat generation.

You must also consider the starting current of your vacuum pump which may be three times its running current.

B. Battery Systems

When using batteries to power vacuum pumps you must consider the continuous run time you need to get from your battery system.

Use the following table and equation to determine your battery requirements after you establish how many watt-hours of power you need from the system.

Example: You have a DC operated vacuum pump that uses 250 watts per hour. Your want to continuously operate your vacuum pump for 8 hours. The watt-hrs you need from your battery system is 250 watts times 8 hours (2,000 watt-hrs).

Battery Type	Watt-hrs per kg battery weight	Battery Type	Watt-hrs per kg battery weight
Li-Ion	135	NiCd	47
NiMH	78	Alkaline	80
NiZn	52	Lead Acid	37

The batteries with the highest power density will be the lightest for your application but the price will be the highest. The lowest price for a battery system will be Lead Acid but will be the heaviest battery system.

If your vacuum pump is AC operated then you must factor in a DC to AC converter which increase the system cost and weight. You will also have a power conversion factor of around 90% so you will need extra battery power.

C. Generators

Generators can be an effective way of powering portable or temporary air sampling equipment.

Use the following table and equation to determine your generator capacity requirements and time between refueling of your generator fuel tank.

Example: You have a vacuum pump that uses 750 watts per hour. Your want to continuously operate your vacuum pump for 8 hours. You need a generator with more than 750 watts generating capacity and the watt-hrs you need from your generator is 750 watts times 8 hours (6,000 watt-hrs).

Typical gasoline generators will deliver about 3,000 watt-hrs per gallon of fuel. If you choose a gasoline generator with a capacity of 1,000 watts or more your generator would use about 2 gallons of fuel to operate your vacuum pump for 8 hours continuously.

Typical diesel generators will deliver about 10,000 watt-hrs per gallon of fuel. If you choose a gasoline generator with a capacity of 1,000 watts or more your generator would use less than 1 gallon of fuel to operate your vacuum pump for 8 hours continuously.

Gasoline powered generators are readily available with capacities from less than 1,000 watts up to 10,000 watts. Diesel powered generators are readily available with capacities from about 5,000 watts up to 20,000 watts. Diesel generators tend to be heavier and more expensive than the gasoline equivalent.

D. Solar Power

Solar power panels can be an effective way to power a remote air monitoring system.

If you want to operate the system continuously you need to add a battery system. Use previous guidance from the section on battery systems to determine the required size of the battery system.

Solar cells produce 5 to 15 watts per square foot of panel depending on the quality of the panels, orientation of the panels, geographic location, and season of the year. The purchase cost of solar power panels ranges from about $7 per watt to $10 per watt. The installation cost of your system must also be considered.

Example: You have a vacuum pump that uses 750 watts per hour. Your sunlight availability at the location is 6 hours per day. You want to continuously operate your vacuum pump and you want to plan for a lack of useable sunlight for only one day. You need a battery system that will operate the vacuum pump for 36 or more hours, but then you must also size the solar panel system to generate enough power to operate the vacuum pump and recharge the battery system. You need 750 watts per hour times 24 hours or 18,000 watt-hours per day from your solar panels. You also need to store a minimum of 18 hours in the battery system in order to operate your air sample pump when there is no sunlight. Your battery system needs to store 750 watts times 18 hours or 13,500 watt-hours just to operate overnight. You must double that battery storage capacity if you need to operate for an extra day without useable sunlight for you solar panels.

How many square feet of solar panel do you need?

Example: From our previous example you need a minimum of 18,000 watt-hours per day from your solar panels. With 6 hours per day of available sunlight you need to collect 3,000 watts per hour. Your solar panels may have a capacity of 10 watts per square foot. Therefore you need 300 square feet of solar panels for this example. My wife and I use 20,000 watt-hours per day at our home and that is fairly typical for a small home in northern New Mexico.

18,000 watt-hrs / 6 hours = 3,000 watts per hour
3,000 watts / 10 watts per square foot = 300 square feet

Refer to the National Renewable Energy Laboratory website at WWW.NREL.GOV for a map depicting solar power availability in the US.

E. Wind Power

Wind power systems are an attractive option as a way to power a remote air monitoring system.

If you want to operate the system when there is not enough wind you need to add a battery system. Use previous guidance from the section on battery systems and solar panels to determine the required size of the battery system.

Wind power systems are readily available in capacities from a few hundred watts to several thousand watts.

Power from a wind system varies with the square of the rotor diameter and the cube of the wind speed. The wind speed typically is higher at 50 feet and higher above the ground surface than it is at 20 feet above the ground surface.

Example: You have a wind machine with a 12 foot diameter rotor and your wind speed is 20 mph.

Watts = 12 squared times 20 cubed divided by 500
= 144 times 8,000 divided by 500
= 2,300 watts

If this wind system generated this much power for 8 hours per day you could operate the air sampling system in the previous example continuously with the appropriate battery system.

Refer to the National Renewable Energy Laboratory website at WWW.NREL.GOV for a map depicting wind power availability in the US.

29CFR1910.1000 Air contaminants.
An employee's exposure to any substance listed in Tables Z–1, Z–2, or Z–3 of this section shall be limited in accordance with the requirements of the following paragraphs of this section.

(a) *Table Z–1*—(1) *Substances with limits preceded by ''C''—Ceiling Values.* An employee's exposure to any substance in Table Z–1, the exposure limit of which is preceded by a ''C'', shall at no time exceed the exposure limit given for that substance. If instantaneous monitoring is not feasible, then the ceiling shall be assessed as a 15-minute time weighted average exposure which shall not be exceeded at any time during the working day.

(2) *Other substances—8-hour Time Weighted Averages.* An employee's exposure to any substance in Table Z–1, the exposure limit of which is not preceded by a ''C'', shall not exceed the 8-hour Time Weighted Average given for that substance in any 8-hour work shift of a 40-hour work week.

(b) *Table Z–2.* An employee's exposure to any substance listed in Table Z–2 shall not exceed the exposure limits specified as follows:

(1) *8-hour time weighted averages.* An employee's exposure to any substance listed in Table Z–2, in any 8-hour work shift of a 40-hour work week, shall not exceed the 8-hour time weighted average limit given for that substance in Table Z–2.

(2) *Acceptable ceiling concentrations.* An employee's exposure to a substance listed in Table Z–2 shall not exceed at any time during an 8-hour shift the acceptable ceiling concentration limit given for the substance in the table, except for a time period, and up to a concentration not exceeding the maximum duration and concentration allowed in the column under ''acceptable maximum peak above the acceptable ceiling concentration for an 8-hour shift."

(3) *Example.* During an 8-hour work shift, an employee may be exposed to a concentration of Substance A (with a 10 ppm TWA, 25 ppm ceiling and 50 ppm peak) above 25 ppm (but never above 50 ppm) only for a maximum period of 10 minutes. Such exposure must be compensated by exposures to concentrations less than 10 ppm so that the cumulative exposure for the entire 8-hour work shift does not exceed a weighted average of 10 ppm.

(c) *Table Z–3.* An employee's exposure to any substance listed in Table Z–3, in any 8-hour work shift of a 40-hour work week, shall not exceed the 8-hour time weighted average limit given for that substance in the table.

(d) *Computation formulae.* The computation formula which shall apply to employee exposure to more than one substance for which 8-hour time weighted averages are listed in subpart Z of 29 CFR part 1910 in order to determine whether an employee is exposed over the regulatory limit is as follows:

(1)(i) The cumulative exposure for an 8-hour work shift shall be computed as follows:

$E = (C_a T_a + C_b T_b + \ldots C_n T_n) / 8$

Where:

E is the equivalent exposure for the working shift.

C is the concentration during any period of time T where the concentration remains constant.

T is the duration in hours of the exposure at the concentration C.

The value of E shall not exceed the 8-hour time weighted average specified in subpart Z of 29 CFR part 1910 for the substance involved.

(ii) To illustrate the formula prescribed in paragraph (d)(1)(i) of this section, assume that Substance A has an 8-hour time weighted average limit of 100 ppm noted in Table Z–1. Assume that an employee is subject to the following exposure:

Two hours exposure at 150 ppm
Two hours exposure at 75 ppm
Four hours exposure at 50 ppm

Substituting this information in the formula, we have

$(2 \times 150 + 2 \times 75 + 4 \times 50) / 8 = 81.25$ ppm

Since 81.25 ppm is less than 100 ppm, the 8-hour time weighted average limit, the exposure is acceptable.

(2)(i) In case of a mixture of air contaminants an employer shall compute the equivalent exposure as follows:

$E_m=(C_1 / L_1 + C_2 / L_2)+. . .(C_n / L_n)$

Where:

E_m is the equivalent exposure for the mixture.
C is the concentration of a particular contaminant.
L is the exposure limit for that substance specified in subpart Z of 29 CFR part 1910.
The value of Em shall not exceed unity (1).

(ii) To illustrate the formula prescribed in paragraph (d)(2)(i) of this section, consider the following exposures:

Substance	Actual concentration of 8-hour exposure (ppm)	8-hour TWA PEL (ppm)
B	500	1,000
C	45	200
D	40	200

Substituting in the formula, we have:

$E_m = 500 / 1,000 + 45 / 200 + 40 / 200$

$E_m = 0.500 + 0.225 + 0.200 = 0.925$

Since E_m is less than unity (1), the exposure combination is within acceptable limits.

(e) To achieve compliance with paragraphs (a) through (d) of this section, administrative or engineering controls must first be determined and implemented whenever feasible. When such controls are not feasible to achieve full compliance, protective equipment or any other protective measures shall be used to keep the exposure of employees to air contaminants within the limits prescribed in this section. Any equipment and/or technical measures used for this purpose must be approved for each particular use by a competent industrial hygienist or other technically qualified person. Whenever respirators are used, their use shall comply with 1910.134.

29CFR1910.134

TABLE 1—ASSIGNED PROTECTION FACTORS (5)

Type of respirator (1, 2)	Quarter mask	Half mask	Full facepiece	Helmet/hood	Loose-fitting facepiece
1. Air-Purifying Respirator	5	(3) 10	50	....	....
2. Powered Air-Purifying Respirator (PAPR)	....	50	1,000	(4) 25/1,000	25
3. Supplied-Air Respirator (SAR) or Airline Respirator					
Demand mode	....	10	50	....	....
Continuous flow mode	....	50	1,000	(4) 25/1,000	25
Pressure-demand or other positive-pressure mode	....	50	1,000	....	....
4. Self-Contained Breathing Apparatus (SCBA)					
Demand mode	....	10	50	50	....
Pressure-demand or other positive-pressure mode (e.g., open/closed circuit)	....	....	10,000	10,000	....

Notes:

(1) Employers may select respirators assigned for use in higher workplace concentrations of a hazardous substance for use at lower concentrations of that substance, or when required respirator use is independent of concentration.

(2) The assigned protection factors in Table 1 are only effective when the employer implements a continuing, effective respirator program as required by this section (29CFR 1910.134), including training, fit testing, maintenance, and use requirements.

(3) This APF category includes filtering facepieces, and half masks with elastomeric facepieces.

(4) The employer must have evidence provided by the respirator manufacturer that testing of these respirators demonstrates performance at a level of protection of 1,000 or greater to receive an APF of 1,000. This level of performance can best be demonstrated by performing a WPF or SWPF study or equivalent testing. Absent such testing, all other PAPRs and SARs with helmets/hoods are to be treated as loose-fitting facepiece respirators, and receive an APF of 25.

(5) These APFs do not apply to respirators used solely for escape. For escape respirators used in association with specific substances covered by 29 CFR 1910 subpart Z, employers must refer to the appropriate substance-specific standards in that subpart.
Escape respirators for other IDLH atmospheres are specified by 29 CFR 1910.134 (d)(2)(ii).

Substance	CAS No.	ppm	mg/m^3	
Acetaldehyde	75-07-0	200	360	
Acetic Acid	64-19-7	10	25	
Acetic anhydride	108-24-7	5	20	
Acetone	67-64-1	1000	2400	
Acetonitrile	75-05-8	40	70	
2-Acetylaminofluorene; see 1910.1014	53-63-3			
Acetylene dichloride; see 1,2-Dichlorethylene				
Acetylene tetrabromide	79-27-6	1	14	
Acrolein	107-02-8	0.1	0.25	
Acrylamide	79-06-1	......	0.3	X
Acrylonitrile; see 1910.1045	107-13-1			
Aldrin	309-00-2	......	0.25	X
Allyl alcohol	107-18-6	2	5	X
Allyl chloride	107-05-1	1	3	X
Allyl glycidyl ether (AGE)	106-92-3	C 10	C 45	
Allyl propyl disulfide	2179-59-1	2	12	
alpha-Alumina	1344-28-1		15	
Total dust		......		
Respirable fraction		......	5	
Aluminum Metal (as Al)	7429-90-5			
Total dust		......	15	
Respirable fraction		......	5	
4-Aminodiphenyl; see 1910.1011	92-67-1			
2-Aminoethanol; see Ethanolamine	504-29-0	0.5	2	
Ammonia	7664-41-7	50	35	
Ammonium sulfamate	7773-06-0			
Total dust		......	15	
Respirable fraction		......	5	

Substance	CAS No.	ppm	mg/m^3	
n-Amyl acetate	628-63-7	100	525	
sec-Amyl acetate	626-38-0	125	650	
Aniline and homologs	62-53-3	5	19	X
Anisidine (o-,p-isomers)	29191-52-4	......	0.5	X
Antimony & compounds as Sb	7440-36-0	......	0.5	
ANTU (alpha Naphthylthiourea)	86-88-4	......	0.3	
Arsenic, inorganic compounds (as As); see 1910.1018	7440-38-2			
Arsenic, organic compounds (as As)	7440-38-2	......	0.5	
Arsine	7784-42-11	0.05	0.2	
Asbestos; see 1910.1001	(4)			
Azinphos-methyl	86-50-0	......	0.2	X
Barium, soluble compounds (as Ba)	7440-39-3	......	0.5	
Barium sulfate	7727-43-7			
Total dust		......	15	
Respirable fraction		......	5	
Benomyl	17804-35-2			
Total dust		......	15	
Respirable fraction		......	5	
Benzene; See 1910.1028 See Table Z-2 for the limits applicable in the operations or sectors excluded in 1910.1028(d)	71-43-2			
Benzidine; See 1910.1010	92-87-5			
p-Benzoquinone; see Quinone				
Benzo(a)pyrene; see Coal tar pitch volatiles				
Benzoyl peroxide	94-36-0	......	5	

Substance	CAS No.	ppm	mg/m^3	
Benzyl chloride	100-44-7	1	5	
Beryllium and beryllium compounds (as Be)	7440-41-7		(2)	
Biphenyl; see Diphenyl				
Bismuth telluride,				
Undoped	1304-82-1			
Total dust		......	15	
Respirable fraction		......	5	
Boron oxide	1303-86-2			
Total dust		......	15	
Boron trifluoride	7637-07-2	C 1	C 3	
Bromine	7726-95-6	0.1	0.7	
Bromoform	75-25-2	0.5	5	X
Butadiene (1,3-Butadiene); See 29 CFR 1910.1051; 29 CFR 1910.19(1)	106-99-0	1 ppm/ 5ppm STEL		
Butanethiol; see Butyl mercaptan				
2-Butanone (Methyl ethyl ketone)	78-93-3	200	590	
2-Butoxyethanol	111-76-2	50	240	X
n-Butyl-acetate	123-86-4	150	710	
sec-Butyl acetate	105-46-4	200	950	
tert-Butyl-acetate	540-88-5	200	950	
n-Butyl alcohol	71-36-3	100	300	
sec-Butyl alcohol	78-92-2	150	450	
tert-Butyl alcohol	75-65-0	100	300	
Butylamine	109-73-9	C 5	C 15	X
tert-Butyl chromate (as CrO(3) see 1910.1026	1189-85-1			
n-Butyl glycidyl ether (BGE)	2426-08-6	50	270	
Butyl mercaptan	109-75-5	10	35	
p-tert-Butyltoluene	98-51-1	10	60	

Substance	CAS No.	ppm	mg/m^3	
Cadmium (as Cd); see 1910.1027	7440-43-9			
Calcium Carbonate	1317-65-3			
Total dust		......	15	
Respirable fraction		......	5	
Calcium hydroxide	1305-62-0			
Total dust		......	15	
Respirable fraction		......	5	
Calcium oxide	1305-78-8	......	5	
Calcium silicate	1344-95-2			
Total dust		......	15	
Respirable fraction		......	5	
Calcium sulfate	7778-18-9			
Total dust		......	15	
Respirable fraction		......	5	
Camphor, synthetic	76-22-2	......	2	
Carbaryl (Sevin)	63-25-2	......	5	
Carbon black	1333-86-4	......	3.5	
Carbon dioxide	124-38-9	5000	9000	
Carbon disulfide	75-15-0		(2)	
Carbon monoxide	630-08-0	50	55	
Carbon tetrachloride	56-23-5		(2)	
Cellulose	9004-34-6			
Total dust		......	15	
Respirable fraction		......	5	
Chlordane	57-74-9	......	0.5	X
Chlorinated camphene	8001-35-2	......	0.5	X
Chlorinated diphenyl oxide	55720-99-5	......	0.5	
Chlorine	7782-50-5	C 1	C 3	
Chlorine dioxide	10049-04-4	0.1	0.3	
Chlorine trifluoride	7790-91-2	C 0.1	C 0.4	

Substance	CAS No.	ppm	mg/m^3	
Chloroacetaldehyde	107-20-0	C 1	C 3	
a-Chloroacetophenone (Phenacyl chloride)	532-27-4	0.05	0.3	
Chlorobenzene	108-90-7	75	350	
o-Chlorobenzylidene malononitrile	2698-41-1	0.05	0.4	
Chlorobromomethane	74-97-5	200	1050	
2-Chloro-1,3-butadiene; See beta-Chloroprene				
Chlorodiphenyl (42% Chlorine)(PCB)	53469-21-9	......	1	X
Chlorodiphenyl (54% Chlorine)(PCB)	11097-69-1	......	0.5	
1-Chloro-2,3-epoxypropane; See Epichlorohydrin				
2-Chloroethanol; See Ethylene chlorohydrin				
Chloroethylene; See Vinyl chloride				
Chloroform (Trichloromethane)	67-66-3	C 50	C 240	
bis(Chloromethyl) ether; see 1910.1008	542-88-1			
Chloromethyl methyl ether; see 1910.1006	107-30-2			
1-Chloro-1-nitropropane|	600-25-9	20	100	
Chloropicrin	76-06-2	0.1	0.7	
beta-Chloroprene	126-99-8	25	90	X
2-Chloro-6 (trichloromethyl) pyridine	1929-82-4			
Total dust		......	15	
Respirable fraction		......	5	

Substance	CAS No.	ppm	mg/m^3
Chromic acid and chromates (as CrO(3))	(4)		(2)
Chromium (II) compounds as Cr	7440-47-3	......	0.5
Chromium (III) compounds as Cr	7440-47-3	......	0.5
Chromium (VI) compounds See 1910.1026(5)			
Chromium metal and insol. salts as Cr	7440-47-3		
Chrysene; see Coal tar pitch volatiles			
Clopidol	2971-90-6		
Total dust		......	15
Respirable fraction		......	5
Coal dust (less than 5% SiO(2)), respirable fraction			(3)
Coal dust (greater than or equal to 5% SiO(2)), respirable fraction			(3)
Coal tar pitch volatiles (benzene soluble fraction), anthracene, BaP, phenanthrene, acridine, chrysene, pyrene	65966-93-2	......	0.2
Cobalt metal, dust, and fume (as Co)	7440-48-4	......	0.1
Coke oven emissions; see 1910.1029			
Copper	7440-050-8		
Fume (as Cu)		......	0.1
Dusts and mists (as Cu)		......	1

Substance	CAS No.	ppm	mg/m^3	
Cotton dust (e), see 1910.1043				
Crag herbicide (Sesone)	136-78-7			
Total dust		......	15	
Respirable fraction		......	5	
Cresol, all isomers	1319-77-3	5	22	X
Crotonaldehyde	123-73-9 4170-30-3	2	6	
Cumene	98-82-8	50	245	X
Cyanides (as CN)	(4)	......	5	X
Cyclohexane	110-82-7	300	1050	
Cyclohexanol	108-93-0	50	200	
Cyclohexanone	108-94-1	50	200	
Cyclohexene	110-83-8	300	1015	
Cyclopentadiene	542-92-7	75	200	
2,4-D (Dichlorophen-oxyacetic acid)	94-75-7	......	10	
Decaborane	17702-41-9	0.05	0.3	X
Demeton (Systox)	8065-48-3	......	0.1	X
Diacetone alcohol (4-Hydroxy-4-methyl-2-pentanone)	123-42-2	50	240	
1,2-Diaminoethane; see Ethylenediamine				
Diazomethane	334-88-3	0.2	0.4	
Diborane	19287-45-7	0.1	0.1	
1,2-Dibromo-3-chloropropane (DBCP); see 1910.1044	96-12-8			
1,2-Dibromoethane; see Ethylene dibromide				
Dibutyl phosphate	107-66-4	1	5	
Dibutyl phthalate	84-74-2	......	5	
o-Dichlorobenzene	95-50-1	C 50	C 300	

Substance	CAS No.	ppm	mg/m3	
p-Dichlorobenzene	106-46-7	75	450	
3,3'-Dichlorobenzidine; see 1910.1007	91-94-1			
Dichlorodifluoromethane	75-71-8	1000	4950	
1,3-Dichloro-5,5-dimethyl hydantoin	118-52-5	......	0.2	
Dichlorodiphenyltri-chloroethane (DDT)	50-29-3	......	1	X
1,1-Dichloroethane	75-34-3	100	400	
1,2-Dichloroethane; see Ethylene dichloride				
1,2-Dichloroethylene	540-59-0	200	790	
Dichloroethyl ether	111-44-4	C 15	C 90	X
Dichloromethane; see Methylene chloride				
Dichloromonofluoro-methane	75-43-4	1000	4200	
1,1-Dichloro-1-nitroethane	594-72-9	C 10	C 60	
1,2-Dichloropropane; see Propylene dichloride				
Dichlorotetrafluoro-ethane	76-14-2	1000	7000	
Dichlorvos (DDVP)	62-73-7	......	1	X
Dicyclopentadienyl iron	102-54-5			
Total dust		......	15	
Respirable fraction		......	5	
Dieldrin	60-57-1	......	0.25	X
Diethylamine	109-89-7	25	75	
2-Diethylaminoethanol	100-37-8	10	50	X
Diethyl ether; see Ethyl ether				
Difluorodibromomethane	75-61-6	100	860	
Diglycidyl ether (DGE)	2238-07-5	C 0.5	C 2.8	

Substance	CAS No.	ppm	mg/m³	
Dihydroxybenzene; see Hydroquinone				
Diisobutyl ketone	108-83-8	50	290	
Diisopropylamine	108-18-9	5	20	X
4-Dimethylaminoazo-benzene; see 1910.1015	60-11-7			
Dimethoxymethane; see Methylal				
Dimethyl acetamide	127-19-5	10	35	X
Dimethylamine	124-40-3	10	18	
Dimethylaminobenzene; see Xylidine				
Dimethylaniline (N,N-Dimethylaniline)	121-69-7	5	25	X
Dimethylbenzene; see Xylene				
Dimethyl-1,2-dibromo-2, 2-dichloroethyl phosphate	300-76-5	......	3	
Dimethylformamide	68-12-2	10	30	X
2,6-Dimethyl-4-heptanone; see Diisobutyl ketone				
1,1-Dimethylhydrazine	57-14-7	0.5	1	X
Dimethylphthalate	131-11-3	......	5	
Dimethyl sulfate	77-78-11	1	5	X
Dinitrobenzene (all isomers)			1	X
(ortho)	528-29-0			
(meta)	99-65-0			
(para)	100-25-4			
Dinitro-o-cresol	534-52-1	......	0.2	X
Dinitrotoluene	25321-14-6	......	1.5	X
Dioxane (Diethylene dioxide)	123-91-1	100	360	X
Diphenyl (Biphenyl)	92-52-4	0.2	1	

Substance	CAS No.	ppm	mg/m^3	
Diphenylmethane diisocyanate; see Methylene bisphenyl isocyanate				
Dipropylene glycol methyl ether	34590-94-8	100	600	X
Di-sec octyl phthalate (Di-(2-ethylhexyl) phthalate)	117-81-7	......	5	
Emery	12415-34-8			
Total dust		......	15	
Respirable fraction		......	5	
Endrin	72-20-8	......	0.1	X
Epichlorohydrin	106-89-8	5	19	X
EPN	2104-64-5	......	0.5	X
1,2-Epoxypropane; see Propylene oxide				
2,3-Epoxy-1-propanol; see Glycidol				
Ethanethiol; see Ethyl mercaptan				
Ethanolamine	141-43-5	3	6	
2-Ethoxyethanol (Cellosolve)	110-80-5	200	740	X
2-Ethoxyethyl acetate (Cellosolve acetate)	111-15-9	100	540	X
Ethyl acetate	141-78-6	400	1400	
Ethyl acrylate	140-88-5	25	100	X
Ethyl alcohol (Ethanol)	64-17-5	1000	1900	
Ethylamine	75-04-7	10	18	
Ethyl amyl ketone (5-Methyl-3-heptanone)	541-85-5	25	130	
Ethyl benzene	100-41-4	100	435	
Ethyl bromide	74-96-4	200	890	

Substance	CAS No.	ppm	mg/m^3	
Ethyl butyl ketone (3-Heptanone)	106-35-4	50	230	
Ethyl chloride	75-00-3	1000	2600	
Ethyl ether	60-29-7	400	1200	
Ethyl formate	109-94-4	100	300	
Ethyl mercaptan	75-08-1	C 10	C 25	
Ethyl silicate	78-10-4	100	850	
Ethylene chlorohydrin	107-07-3	5	16	X
Ethylenediamine	107-15-3	10	25	
Ethylene dibromide	106-93-4		(2)	
Ethylene dichloride (1,2-Dichloroethane)	107-06-2		(2)	
Ethylene glycol dinitrate	628-96-6	C 0.2	C 1	X
Ethylene glycol methyl acetate; see Methyl cellosolve acetate				
Ethyleneimine; see 1910.1012	151-56-4			
Ethylene oxide; see 1910.1047	75-21-8			
Ethylidene chloride; see 1,1-Dichlorethane				
N-Ethylmorpholine	100-74-3	20	94	X
Ferbam Total dust	14484-64-1	......	15	
Ferrovanadium dust	12604-58-9	......	1	
Fluorides (as F)	(4)	......	2.5	
Fluorine	7782-41-4	0.1	0.2	
Fluorotrichloromethane (Trichloro- fluoromethane)	75-69-4	1000	5600	
Formaldehyde; see 1910.1048	50-00-0			
Formic acid	64-18-6	5	9	
Furfural	98-01-1	5	20	X
Furfuryl alcohol	98-00-0	50	200	
Grain dust (oat, wheat barley)		......	10	

Substance	CAS No.	ppm	mg/m^3	
Glycerin (mist)	56-81-5			
Total dust		......	15	
Respirable fraction		......	5	
Glycidol	556-52-5	50	150	
Glycol monoethyl ether; see 2-Ethoxyethanol				
Graphite, natural respirable dust	7782-42-5		-3	
Graphite, synthetic				
Total dust		......	15	
Respirable fraction		......	5	
Guthion; see Azinphos methyl				
Gypsum	13397-24-5			
Total dust		......	15	
Respirable fraction		......	5	
Hafnium	7440-58-6	......	0.5	
Heptachlor	76-44-8	......	0.5	X
Heptane (n-Heptane)	142-82-5	500	2000	
Hexachloroethane	67-72-1	1	10	X
Hexachloronaphthalene	1335-87-1	......	0.2	X
n-Hexane	110-54-3	500	1800	
2-Hexanone (Methyl n-butyl ketone)	591-78-6	100	410	
Hexone (Methyl isobutyl ketone)	108-10-1	100	410	
sec-Hexyl acetate	108-84-9	50	300	
Hydrazine	302-01-2	1	1.3	X
Hydrogen bromide	10035-10-6	3	10	
Hydrogen chloride	7647-01-0	C 5	C 7	
Hydrogen cyanide	74-90-8	10	11	X
Hydrogen fluoride (as F)	7664-39-3		(2)	
Hydrogen peroxide	7722-84-1	1	1.4	

Substance	CAS No.	ppm	mg/m^3	
Hydrogen selenide (as Se)	2148906	0.05	0.2	
Hydrogen sulfide	7783-06-4		(2)	
Hydroquinone	123-31-9	......	2	
Iodine	7553-56-2	C 0.1	C 1	
Iron oxide fume	1309-37-1	......	10	
Isomyl acetate	123-92-2	100	525	
Isomyl alcohol (primary and secondary)	123-51-3	100	360	
Isobutyl acetate	110-19-0	150	700	
Isobutyl alcohol	78-83-1	100	300	
Isophorone	78-59-1	25	140	
Isopropyl acetate	108-21-4	250	950	
Isopropyl alcohol	67-63-0	400	980	
Isopropylamine	75-31-0	5	12	
Isopropyl ether	108-20-3	500	2100	
Isopropyl glycidyl ether (IGE)	4016-14-2	50	240	
Kaolin	1332-58-7			
Total dust		......	15	
Respirable fraction		......	5	
Ketene	463-51-4	0.5	0.9	
Lead inorganic (as Pb); see 1910.1025	7439-92-1			
Limestone	1317-65-3			
Total dust		......	15	
Respirable fraction		......	5	
Lindane	58-89-9	......	0.5	X
Lithium hydride	7580-67-8	......	0.025	
LP.G (Liquified petroleum gas)	68476-85-7	1000	1800	
Magnesite	546-93-0			
Total dust		......	15	
Respirable fraction		......	5	

Substance	CAS No.	ppm	mg/m^3	
Magnesium oxide fume	1309-48-4			
Total Particulate		......	15	
Malathion	121-75-5			
Total dust		......	15	
Maleic anhydride	108-31-6	0.25	1	
Manganese compounds (as Mn)	7439-96-5	......	C 5	
Manganese fume (as Mn)	7439-96-5	......	C 5	
Marble	1317-65-3			
Total dust		......	15	
Respirable fraction		......	5	
Mercury (aryl and inorganic) (as Hg)	7439-97-6		(2)	
Mercury (organo) alkyl compounds (as Hg)	7439-97-6		(2)	
Mercury (vapor) (as Hg)	7439-97-6		(2)	
Mesityl oxide	141-79-7	25	100	
Methanethiol; see Methyl mercaptan				
Methoxychlor Total dust	72-43-5	......	15	
2-Methoxyethanol; (Methyl cellosolve)	109-86-4	25	80	X
2-Methoxyethyl acetate (Methyl cellosolve acetate)	110-49-6	25	120	X
Methyl acetate	79-20-9	200	610	
Methyl acetylene (Propyne)	74-99-7	1000	1650	
Methyl acetylene propadiene mixture (MAPP)		1000	1800	
Methyl acrylate	96-33-3	10	35	X
Methylal (Dimethoxy-methane)	109-87-5	1000	3100	
Methyl alcohol	67-56-1	200	260	
Methylamine	74-89-5	10	12	

Substance	CAS No.	ppm	mg/m³	
Methyl amyl alcohol; see Methyl Isobutyl carbinol				
Methyl n-amyl ketone	110-43-0	100	465	
Methyl bromide	74-83-9	C 20	C 80	X
Methyl butyl ketone; see 2-Hexanone				
Methyl cellosolve; see 2-Methoxyethanol				
Methyl cellosolve acetate; see 2-Methoxyethyl acetate				
Methyl chloride	74-87-3		(2)	
Methyl chloroform (1,1,1-Trichloro-ethane)	71-55-6	350	1900	
Methylcyclohexane	108-87-2	500	2000	
Methylcyclohexanol	25639-42-3	100	470	
o-Methylcyclohexanone	583-60-8	100	460	X
Methylene chloride	75-09-2		(2)	
Methyl ethyl ketone (MEK); see 2-Butanone				
Methyl formate	107-31-3	100	250	
Methyl hydrazine (Monomethyl hydrazine)	60-34-4	C 0.2	C 0.35	X
Methyl iodide	74-88-4	5	28	X
Methyl isoamyl ketone	110-12-3	100	475	
Methyl isobutyl carbinol	108-11-2	25	100	X
Methyl isobutyl ketone; see Hexone				
Methyl isocyanate	624-83-9	0.02	0.05	X
Methyl mercaptan	74-93-1	C 10	C 20	
Methyl methacrylate	80-62-6	100	410	

Substance	CAS No.	ppm	mg/m^3	
Methyl propyl ketone; see 2-Pentanone				
alpha-Methyl styrene	98-83-9	C 100	C 480	
Methylene bisphenyl isocyanate (MDI)	101-68-8	C 0.02	C 0.2	
Mica; see Silicates				
Molybdenum (as Mo)	7439-98-7			
Soluble compounds		......	5	
Insoluble Compounds				
Total dust		......	15	
Monomethyl aniline	100-61-8	2	9	X
Monomethyl hydrazine; see Methyl hydrazine				
Morpholine	110-91-8	20	70	X
Naphtha (Coal tar)	8030-30-6	100	400	
Naphthalene	91-20-3	10	50	
alpha-Naphthylamine; see 1910.1004	134-32-7			
beta-Naphthylamine; see 1910.1009	91-59-8			
Nickel carbonyl (as Ni)	13463-39-3	0.001	0.007	
Nickel, metal and insoluble compounds (as Ni)	7440-02-0	......	1	
Nickel, soluble compounds (as Ni)	7440-02-0	......	1	
Nicotine	54-11-5	......	0.5	X
Nitric acid	7697-37-2	2	5	
Nitric oxide	10102-43-9	25	30	
p-Nitroaniline	100-01-6	1	6	X
Nitrobenzene	98-95-3	1	5	X
p-Nitrochlorobenzene	100-00-5	......	1	X

Substance	CAS No.	ppm	mg/m3	
4-Nitrodiphenyl; see 1910.1003	92-93-3			
Nitroethane	79-24-3	100	310	
Nitrogen dioxide	10102-44-0	C 5	C 9	
Nitrogen trifluoride	7783-54-2	10	29	
Nitroglycerin	55-63-0	C 0.2	C 2	X
Nitromethane	75-52-5	100	250	
1-Nitropropane	108-03-2	25	90	
2-Nitropropane	79-46-9	25	90	
N-Nitrosodimethylamine; see 1910.1016				
Nitrotoluene (all isomers)		5	30	X
o-isomer	88-72-2			
m-isomer	99-99-0			
p-isomer	99-08-1			
Nitrotrichloromethane; see Chloropicrin				
Octachloronaphthalene	2234-13-1	......	0.1	X
Octane	111-65-9	500	2350	
Oil mist, mineral	8012-95-1	......	5	
Osmium tetroxide (as Os)	20816-12-0	......	0.002	
Oxalic acid	144-62-7	......	1	
Oxygen difluoride	7783-41-7	0.05	0.1	
Ozone	10028-15-6	0.1	0.2	
Paraquat, respirable dust	4685-14-7 1910-42-5 2074-50-2	......	0.5	X
Parathion	56-38-2	......	0.1	X
Particulates not otherwise regulated (PNOR)(f)				
Total dust		......	15	
Respirable fraction		......	5	

Substance	CAS No.	ppm	mg/m³	
PCB; see Chlorodiphenyl (42% and 54% chlorine)				
Pentaborane	19624-22-7	0	0.01	
Pentachloronaphthalene	1321-64-8	......	0.5	X
Pentachlorophenol	87-86-5	......	0.5	X
Pentaerythritol	115-77-5			
Total dust		......	15	
Respirable fraction		......	5	
Pentane	109-66-0	1000	2950	
2-Pentanone (Methyl propyl ketone)	107-87-9	200	700	
Perchloroethylene (Tetrachloroethylene)	127-18-4		(2)	
Perchloromethyl mercaptan	594-42-3	0.1	0.8	
Perchloryl fluoride	7616-94-6	3	13.5	
Petroleum distillates (Naphtha) (Rubber Solvent)		500	2000	
Phenol	108-95-2	5	19	X
p-Phenylene diamine	106-50-3	......	0.1	X
Phenyl ether, vapor	101-84-8	1	7	
Phenyl ether-biphenyl mixture, vapor		1	7	
Phenylethylene; see Styrene				
Phenyl glycidyl ether (PGE)	122-60-1	10	60	
Phenylhydrazine	100-63-0	5	22	X
Phosdrin (Mevinphos)	7786-34-7	......	0.1	X
Phosgene (Carbonyl chloride)	75-44-5	0.1	0.4	
Phosphine	7803-51-2	0.3	0.4	
Phosphoric acid	7664-38-2	......	1	
Phosphorus (yellow)	7723-14-0	......	0.1	
Phosphorus pentachloride	2968331	......	1	

Substance	CAS No.	ppm	mg/m^3	
Phosphorus pentasulfide	1314-80-3	......	1	
Phosphorus trichloride	7719-12-2	0.5	3	
Phthalic anhydride	85-44-9	2	12	
Picloram	1918-02-1			
Total dust		......	15	
Respirable fraction		......	5	
Picric acid	88-89-1	......	0.1	X
Pindone (2-Pivalyl-1,3-indandione)	83-26-1	......	0.1	
Plaster of paris	26499-65-0			
Total dust		......	15	
Respirable fraction		......	5	
Platinum (as Pt)	7440-06-4			
Metal		......	......	
Soluble Salts		......	0.002	
Portland cement	65997-15-1			
Total dust		......	15	
Respirable fraction		......	5	
Propane	74-98-6	1000	1800	
beta-Propriolactone; see 1910.1013	57-57-8			
n-Propyl acetate	109-60-4	200	840	
n-Propyl alcohol	71-23-8	200	500	
n-Propyl nitrate	627-13-4	25	110	
Propylene dichloride	78-87-5	75	350	
Propylene imine	75-55-8	2	5	X
Propylene oxide	75-56-9	100	240	
Propyne; see Methyl acetylene				
Pyrethrum	8003-34-7	......	5	
Quinone	106-51-4	0.1	0.4	
RDX: see Cyclonite				

Substance	CAS No.	ppm	mg/m^3
Pyridine	110-86-1	5	15
Rhodium (as Rh), metal fume and insoluble compounds	7440-16-6	......	0.1
Rhodium (as Rh), soluble compounds	7440-16-6	......	0.001
Ronnel	299-84-3	......	15
Rotenone	83-79-4	......	5
Rouge			
Total dust		......	15
Respirable fraction		......	5
Selenium compounds (as Se)	7782-49-2	......	0.2
Selenium hexafluoride (as Se)	7783-79-1	0.05	0.4
Silica, amorphous, precipitated and gel	112926-00-8		(3)
Silica, amorphous, diatomaceous earth, containing less than 1% crystalline silica	61790-53-2		(3)
Silica, crystalline cristobalite, respirable dust	14464-46-1		(3)
Silica, crystalline quartz, respirable dust	14808-60-7		(3)
Silica, crystalline tripoli (as quartz), respirable dust	1317-95-9		(3)
Silica, crystalline tridymite, respirable dust	15468-32-3		(3)
Silica, fused, respirable dust	60676-86-0		(3)

Substance	CAS No.	ppm	mg/m^3	
Silicates (less than 1% crystalline silica)				
Mica (respirable dust)	12001-26-2		(3)	
Soapstone, total dust			(3)	
Soapstone, respirable dust			(3)	
Talc (containing asbestos): use asbestos limit: see 29 CFR 1910.1001			(3)	
Talc (containing no asbestos), respirable dust	14807-96-6		(3)	
Tremolite, asbestiform; see 1910.1001				
Silicon	7440-21-3			
Total dust		......	15	
Respirable fraction		......	5	
Silicon carbide	409-21-2			
Total dust		......	15	
Respirable fraction		......	5	
Silver, metal and soluble compounds (as Ag)	7440-22-4	......	0.01	
Soapstone; see Silicates				
Sodium fluoroacetate	62-74-8	......	0.05	X
Sodium hydroxide	1310-73-2	......	2	
Starch	9005-25-8			
Total dust		......	15	
Respirable fraction		......	5	
Stibine	7803-52-3	0.1	0.5	
Stoddard solvent	8052-41-3	500	2900	
Strychnine	57-24-9	......	0.15	
Styrene	100-42-5		(2)	

Substance	CAS No.	ppm	mg/m^3	
Sucrose	57-50-1			
Total dust		......	155	
Respirable fraction		......		
Sulfur dioxide	2025881	5	13	
Sulfur hexafluoride	2551-62-4	1000	6000	
Sulfuric acid	7664-93-9	......	1	
Sulfur monochloride	10025-67-9	1	6	
Sulfur pentafluoride	5714-22-7	0.03	0.25	
Sulfuryl fluoride	2699-79-8	5	20	
Systox; see Demeton				
2,4,5-T (2,4,5-tri- chlorophenoxyacetic acid)	93-76-5	......	10	
Talc; see Silicates				
Tantalum, metal and oxide dust	7440-25-7	......	5	
TEDP (Sulfotep)	3689-24-5	......	0.2	X
Tellurium & compounds (as Te)	13494-80-9	......	0.1	
Tellurium hexafluoride (as Te)	7783-80-4	0.02	0.2	
Temephos	3383-96-8			
Total dust		......	155	
Respirable fraction		......		
TEPP (Tetraethyl pyrophosphate)	107-49-3	......	0.05	X
Terphenylis	26140-60-3	C 1	C 9	
1,1,1,2-Tetrachloro-2, 2-difluoroethane	76-11-9	500	4170	
1,1,2,2-Tetrachloro-1, 2-difluoroethane	76-12-0	500	4170	
1,1,2,2-Tetrachloro- ethane	79-34-5	5	35	X
Tetrachoroethylene; see Perchloroethylene				

Substance	CAS No.	ppm	mg/m3	
Tetrachloromethane; see Carbon tetrachloride				
Tetrachloronaphthalene	1335-88-2	......	2	X
Tetraethyl lead (as Pb)	78-00-2	......	0.08	X
Tetrahydrofuran	109-99-9	200	590	
Tetramethyl lead, (as Pb)	75-74-1	......	0.08	X
Tetramethyl succinonitrile	3333-52-6	0.5	3	X
Tetranitromethane	509-14-8	1	8	
Tetryl (2,4,6-Trinitro-phenylmethyl-nitramine)	479-45-8	......	1.5	X
Thallium, soluble compounds (as Tl)	7440-28-0	......	0.1	X
4,4'-Thiobis(6-tert, Butyl-cresol)	96-69-5			
Total dust		......	15	
Respirable fraction		......	5	
Thiram	137-26-8	......	5	
Tin, inorganic compounds (except oxides) (as Sn)	7440-31-5	......	2	
Tin, organic compounds (as Sn)	7440-31-5	......	0.1	
Titanium dioxide	13463-67-7			
Total dust		......	15	
Toluene	108-88-3		(2)	
Toluene-2,4-diisocyanate (TDI)	584-84-9	C 0.02	C 0.14	
o-Toluidine	95-53-4	5	22	X
Toxaphene; see Chlorinated camphene				
Tremolite; see Silicates				
Tributyl phosphate	126-73-8	......	5	
1,1,1-Trichloroethane; see Methyl chloroform				
1,1,2-Trichloroethane	79-00-5	10	45	X

Substance	CAS No.	ppm	mg/m^3	
Trichloroethylene	79-01-6		(2)	
Trichloromethane; see Chloroform				
Trichloronaphthalene	1321-65-9	......	5	X
1,2,3-Trichloropropane	96-18-4	50	300	
1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1	1000	7600	
Triethylamine	121-44-8	25	100	
Trifluorobromomethane	75-83-8	1000	6100	
2,4,6-Trinitrophenol; see Picric acid				
2,4,6-Trinitrophenyl-methyl nitramine; see Tetryl				
2,4,6-Trinitrotoluene (TNT)	118-96-7	......	1.5	X
Triorthocresyl phosphate	78-30-8	......	0.1	
Triphenyl phosphate	115-86-6	......	3	
Turpentine	8006-64-2	100	560	
Uranium (as U)	7440-61-1			
Soluble compounds		......	0.05	
Insoluble compounds		......	0.25	
Vanadium	1314-62-1			
Respirable dust (as V_2O_5)		......	C 0.5	
Fume (as V_2O_5)		......	C 0.1	
Vegetable oil mist				
Total dust		......	15	
Respirable fraction		......	5	
Vinyl benzene; see Styrene				
Vinyl chloride; see 1910.1017	75-01-4			
Vinyl cyanide; see Acrylonitrile				
Vinyl toluene	25013-15-4	100	480	
Warfarin	81-81-2	......	0.1	

Substance	CAS No.	ppm	mg/m^3	
Xylenes (o-, m-, p-isomers)	1330-20-7	100	435	
Xylidine	1300-73-8	5	25	X
Yttrium	7440-65-5	......	1	
Zinc chloride fume	7646-85-7	......	1	
Zinc oxide fume	1314-13-2	......	5	
Zinc oxide	1314-13-2			
Total dust		......	15	
Respirable fraction		......	5	
Zinc stearate	557-05-1			
Total dust		......	15	
Respirable fraction		......	5	
Zirconium compounds (as Zr)	7440-67-7	......	5	

X indicates a Skin Designation for the substance.
[1] The PELs are 8-hour TWAs unless otherwise noted; a (C) designation denotes a ceiling limit. They are to be determined from breathing-zone air samples.
(a) Parts of vapor or gas per million parts of contaminated air by volume at 25 C and 760 torr.
(b) Milligrams of substance per cubic meter of air. When entry is in this column only, the value is exact; when listed with a ppm entry, it is approximate.
(c) The CAS number is for information only. Enforcement is based on the substance name. For an entry covering more than one metal compound, measured as the metal, the CAS number for the metal is given - not CAS numbers for the individual compounds.

(d) The final benzene standard in 1910.1028 applies to all occupational exposures to benzene except in some circumstances the distribution and sale of fuels, sealed containers and pipelines, coke production, oil and gas drilling and production, natural gas processing, and the percentage exclusion for liquid mixtures; for the excepted subsegments, the benzene limits in Table Z– apply. See 1910.1028 for specific circumstances.
(e) This 8-hour TWA applies to respirable dust as measured by a vertical elutriator cotton dust sampler or equivalent instrument. The time-weighted average applies to the cotton waste processing operations of waste recycling (sorting, blending, cleaning and willowing) and garnetting. See also 1910.1043 for cotton dust limits applicable to other sectors.
(f) All inert or nuisance dusts, whether mineral, inorganic, or organic, not listed specifically by substance name are covered by the Particulates Not Otherwise Regulated (PNOR) limit which is the same as the inert or nuisance dust limit of Table Z–.
2 See Table Z–.
3 See Table Z–.
4 Varies with compound.
5 See Table Z– for the exposure limit for any operations or sectors where the exposure limit in 1910.1026 is stayed or is otherwise not in effect.
6 If the exposure limit in 1910.1026 is stayed or is otherwise not in effect, the exposure limit is a ceiling of 0.1 mg/m^3.

TABLE Z-2

Substance	8 hr TWA	Acceptable Ceiling	Acceptable max peak above the acceptable ceiling concentration for an 8 hr shift
Benzene [a] (Z37.40-1969)	10 ppm	25 ppm	50 ppm 10 min
Beryllium and beryllium compounds (Z37.29-1970)	2 ug/m^3	5 ug/m^3	25 ug/m^3 30 min
Cadmium fume [b] (Z37.5-1970)	0.1 mg/m^3	0.3 mg/m^3	
Cadmium dust [b] (Z37.5-1970)	0.2 mg/m^3	0.6 mg/m^3	
Carbon disulfide (Z37.3-1968)	20 ppm	30 ppm	100 ppm 30 min
Carbon tetrachloride (Z37.17-1967)	10 ppm	25 ppm	200 ppm 5 min in any 4 hrs
Chromic acid and chromates (Z37.7-1971) (as CrO)		1 mg/10m^3	
Ethylene dibromide (Z37.31-1970)	20 ppm	30 ppm	50 ppm 5 min
Ethylene dichloride (Z37.21-1969)	50 ppm	100 ppm	200 ppm 5 min in any 3 hrs
Fluoride as dust (Z37.28-1969)	25 mg/m^3		
Formaldehyde; see 1910.1048			
Hydrogen fluoride (Z37.28-1969)	3 ppm		

TABLE Z-2

Substance	8 hr TWA	Acceptable Ceiling	Acceptable max peak above the acceptable ceiling concentration for an 8 hr shift
Hydrogen sulfide (Z37.2-1966)	20 ppm	50 ppm	10 min once, if no other meas. exp. occurs
Mercury (Z37.8-1971)	......	1 mg/10m^3	
Methyl chloride (Z37.18-1969)	100 ppm	200 ppm	300 ppm 5 min in any 3 hrs
Methylene Chloride; see 1919.52			
Organo (alkyl) mercury (Z37.30-1969)		0.01 mg/m^3	0.04 mg/m^3
Styrene (Z37.15-1969)	100 ppm	200 ppm	600 ppm 5 min in any 3 hrs
Tetrachloroethylene (Z37.22-1967)	100 ppm	200 ppm	300 ppm 5 min in any 3 hrs
Toluene (Z37.12-1967)	200 ppm	300 ppm	500 ppm 10 min
Trichloroethylene (Z37.19-1967)	100 ppm	200 ppm	300 ppm 5 min in any 2 hrs

[a]This standard applies to the industry segments exempt from the 1 ppm 8-hour TWA and 5 ppm STEL of the benzene standard 1910.1028.

[b]This standard applies to any operations or sectors for which the Cadmium standard, 1910.1027, is stayed or otherwise not in effect.

[c]This standard applies to any operations or sectors for which the exposure limit in the Chromium (VI) standard, 1910.1026, is stayed or is otherwise not in effect.

TABLE Z-3

Substance	ppfc[a]	mg/m³
Silica:		
Crystalline		
Quartz (Respirable)	$\frac{250^{b}}{\%SiO_2 + 5}$	$\frac{10\ mg/m^3}{\%SiO_2 + 2}$ [e]
Quartz (Total Dust)	....	$\frac{30\ mg/m^3}{\%SiO_2 + 2}$
Cristobalite: Use ½ the value calculated from the count or mass formulae for quartz.		
Tridymite: Use ½ the value calculated from the formulae for quartz.		
Amorphous, including natural diatomaceous earth	....	$\frac{80\ mg/m^3}{\%SiO_2}$
Silicates (less than 1% crystalline silica):		
Mica	20	
Soapstone	20	
Talc (not containing asbestos)	20[c]	
Talc (containing asbestos) Use asbestos limit		
Tremolite, asbestiform; see 1910.1001		
Portland cement	50	

TABLE Z-3

Substance	ppfc[a]	mg/m^3
Graphite (Natural)	15	
Coal Dust:		
Respirable fraction less than 5% SiO_2	....	2.4 mg/m^3 [e]
Respirable fraction greater than 5% SiO_2	....	10 mg/m^3 [e] / $\%SiO_2$ +2
Inert or Nusiance Dust:[d]		
Respirable fraction	15	5 mg/m^3
Total dust	50	15 mg/m^3

Note—Conversion factors - mppcf x 35.3 = million particles per m^3 = particles per cc

[a] Millions of particles per cubic foot of air, based on impinger samples counted by light-field techniques.

[b] The percentage of crystalline silica in the formula is the amount determined from airborne samples, except in those instances in which other methods have been shown to be applicable.

[c] Containing less than 1% quartz; if 1% quartz or more, use quartz limit.

[d] All inert or nuisance dusts, whether mineral, inorganic, or organic, not listed specifically by substance name are covered by this limit, which is the same as the Particulates Not Otherwise Regulated (PNOR) limit in Table Z–1.

[e] Both concentration and percent quartz for the application of this limit are to be determined from the fraction passing a sizeselector with the following characteristics:

Aerodynamic diameter (unit density sphere)	Percent passing selector
2	90
2.5	75
3.5	50
5.0	25
10	0

The measurements under this note refer to the use of an NRC instrument. The respirable fraction of coal dust is determined with an MRE; the figure corresponding to that of 2.4 mg/m^3 in the table for coal dust is 4.5 mg/m^3 [K].

10CFR20 “STANDARDS FOR PROTECTION AGAINST RADIATION” and 10CFR835 “OCCUPATIONAL RADIATION PROTECTION” use the following definitions for ALI and DAC.

10CFR20 Specifies Respiratory Protection Factors while 10CFR835 uses those Respiratory Protection Factors specified by 29CFR1910 “OCCUPATIONAL SAFETY AND HEALTH STANDARDS”.

Annual limit on intake (ALI) means the derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year. ALI is the smaller value of intake of a given radionuclide in a year by the reference man (ICRP Publication 23) that would result in a committed effective dose of 5 rems (0.05 sieverts (Sv)) (1 rem = 0.01 Sv) or a committed equivalent dose of 50 rems (0.5 Sv) to any individual organ or tissue.

Derived air concentration (DAC) means, for the radionuclides listed in appendix A of this part, the airborne concentration that equals the ALI divided by the volume of air breathed by an average worker for a working year of 2000 hours (assuming a breathing volume of 2400 m^3).

The following table of Inhalation DAC Factors lists both the 10CFR20 values and the 10CFR835 values for the most restrictive DAC values in uCi/mL. Due to the somewhat different work activities in NRC regulated facilities and the Department of Energy facilities there are some apparent differences. Also 10CFR835 separates out exposures in radioactive clouds while 10CFR20 includes those DAC factors in the main table.

10CFR20 Appendix A

Assigned Protection Factors for Respirators (a)

I. Air Purifying Respirators [Particulate (b) only] (c):

Filtering facepiece disposable (d)	Negative Pressure.....	(d)
Facepiece, half (e)	Negative Pressure	10
Facepiece, full	Negative Pressure	100
Facepiece, half	Powered air-purifying	50
Facepiece, full	Powered air-purifying	1000
Helmet/hood	Powered air-purifying	1000
Facepiece, loose-fitting	Powered air-purifying	25

II. Atmosphere supplying respirators [particulate, gases and vapors (f)]:

1. Air-line respirator:

Facepiece, half	Demand	10
Facepiece, half	Continuous Flow	50
Facepiece, half	Pressure Demand	50
Facepiece, full	Demand	100
Facepiece, full	Continuous Flow	1000
Facepiece, full	Pressure Demand	1000
Helmet/hood	Continuous Flow	1000
Facepiece, loose-fitting	Continuous Flow	25
Suit	Continuous Flow	(g)

2. Self-contained breathing Apparatus (SCBA):

Facepiece, full	Demand	(h) 100
Facepiece, full	Pressure Demand	(i) 10,000
Facepiece, full	Demand, Recirculating	(h)100
Facepiece, full	Positive Pressure Recirculating	(i) 10,000

III. Combination Respirators: Any combination of air-purifying Assigned protection factor for and atmosphere-supplying type and mode of operation as respirators. listed above.

(a) These assigned protection factors apply only in a respiratory protection program that meets the requirements of this Part. They are applicable only to airborne radiological hazards and may not be appropriate to circumstances when chemical or other respiratory hazards exist instead of, or in addition to, radioactive hazards. Selection and use of respirators for such circumstances must also comply with Department of Labor regulations. Radioactive contaminants for which the concentration values in Table 1, Column 3 of Appendix B to Part 20 are based on internal dose due to inhalation may, in addition, present external exposure hazards at higher concentrations. Under these circumstances, limitations on occupancy may have to be governed by external dose limits.

(b) Air purifying respirators with APF <100 must be equipped with particulate filters that are at least 95 percent efficient. Air purifying respirators with APF = 100 must be equipped with particulate filters that are at least 99 percent efficient. Air purifying respirators with APFs >100 must be equipped with particulate filters that are at least 99.97 percent efficient.

(c) The licensee may apply to the Commission for the use of an APF greater than 1 for sorbent cartridges as protection against airborne radioactive gases and vapors (e.g., radioiodine).

(d) Licensees may permit individuals to use this type of respirator who have not been medically screened or fit tested on the device provided that no credit be taken for their use in estimating intake or dose. It is also recognized that it is difficult to perform an effective positive or negative pressure pre-use user seal check on this type of device. All other respiratory protection program requirements listed in Sec. 20.1703 apply. An assigned protection factor has not been assigned for these devices. However, an APF equal to 10 may be used if the licensee can demonstrate a fit factor of at least 100 by use of a validated or evaluated, qualitative or quantitative fit test.

(e) Under-chin type only. No distinction is made in this Appendix between elastomeric half-masks with replaceable cartridges and those designed with the filter medium as an integral part of the facepiece (e.g., disposable or reusable disposable). Both types are acceptable so long as the seal area of the latter contains some substantial type of seal-enhancing material such as rubber or plastic, the two or more suspension straps are adjustable, the filter medium is at least 95 percent efficient and all other requirements of this Part are met.

(f) The assigned protection factors for gases and vapors are not applicable to radioactive contaminants that present an absorption or submersion hazard. For tritium oxide vapor, approximately one-third of the intake occurs by absorption through the skin so that an overall protection factor of 3 is appropriate when atmosphere-supplying respirators are used to protect against tritium oxide. Exposure to radioactive noble gases is not considered a significant respiratory hazard, and protective actions for these contaminants should be based on external (submersion) dose considerations.

(g) No NIOSH approval schedule is currently available for atmosphere supplying suits. This equipment may be used in an acceptable respiratory protection program as long as all the other minimum program requirements, with the exception of fit testing, are met (i.e., Sec. 20.1703).

(h) The licensee should implement institutional controls to assure that these devices are not used in areas immediately dangerous to life or health (IDLH).

(i) This type of respirator may be used as an emergency device in unknown concentrations for protection against inhalation hazards. External radiation hazards and other limitations to permitted exposure such as skin absorption shall be taken into account in these circumstances. This device may not be used by any individual who experiences perceptible outward leakage of breathing gas while wearing the device.

	10CFR20 DAC	10CFR835 DAC		10CFR20 ALIs uCi	
	uCi/mL	uCi/mL	Bq/M^3	Ingestion	Inhalation
H-3[1]	X	2E-05	7E+5	X	X
H-3[2]	X	2E-01	9E+9	X	X
H-3[3]	2E-05	X	X	8E+4	8E+4
STCs[4]	X	2E-06	8E+4	X	X
STCs[5]	X	1E-05	5E+5	X	X
Be-7	8E-06	1E-05	4E+5	4E+4	2E+4
Be-10	6E-09	2E-08	1E+3	1E+3	2E+2
C-11[6, 38]	X	1E-04	6E+6	X	X
C-11[7]	5E-04	4E-04	1E+7	X	1E+6
C-11[8]	3E-04	2E-04	9E+6	X	6E+5
C-11[9]	2E-04	X	X	4E+5	4E+5
C-14[6]	X	9E-07	3E+4	X	X
C-14[7]	7E-04	7E-04	2E+7	X	2E+6
C-14[8]	9E-05	8E-05	3E+6	X	2E+5
C-14[9]	1E-06	X	X	2E+3	2E+3
F-18[38]	3E-05	3E-06	1E+5	5E+4	7E+4
Na-22	3E-07	2E-07	1E+4	4E+2	6E+2
Na-24	2E-06	4E-07	1E+4	4E+3	5E+3
Mg-28	5E-07	3E-07	1E+4	7E+2	1E+3
Al-26	3E-08	4E-08	1E+3	4E+2	60
Si-31	1E-06	5E-06	1E+5	9E+3	3E+4
Si-32	2E-09	1E-08	3E+2	2E+3	5
P-32	2E-07	5E-07	7E+3	6E+2	4E+2
P-33	1E-06	4E-06	1E+4	6E+3	3E+3
S-35[10]	6E-06	4E-06	1E+5	X	1E+4
S-35	9E-07	5E-07	1E+4	6E+3	2E+3
Cl-36	1E-07	1E-07	4E+3	2E+3	2E+2
Cl-38[38]	2E-05	5E-06	2E+5	2E+4	4E+4
Cl-39[38]	2E-05	2E-06	1E+5	2E+4	5E+4
K-40	2E-07	1E-07	6E+3	3E+2	4E+2

	10CFR20 DAC uCi/mL	10CFR835 DAC uCi/mL	Bq/M^3	10CFR20 ALIs uCi Ingestion	Inhalation
K-42[38]	2E-06	2E-06	1E+5	5E+3	5E+3
K-43	4E-06	9E-07	3E+4	6E+3	9E+3
K-44	3E-05	8E-06	2E+5	2E+4	7E+4
K-45[38]	5E-05	9E-06	3E+5	3E+4	1E+5
Ca-41	2E-06	2E-06	8E+4	3E+3	4E+3
Ca-45	4E-07	2E-07	9E+3	2E+3	8E+2
Ca-47	4E-07	2E-07	9E+3	8E+2	9E+2
Sc-43	9E-06	2E-06	7E+4	7E+3	2E+4
Sc-44m	3E-07	2E-07	1E+4	5E+2	7E+2
Sc-44	5E-06	1E-06	4E+4	4E+3	1E+4
Sc-46	1E-07	1E-07	4E+3	9E+2	2E+2
Sc-47	1E-06	7E-07	2E+4	2E+3	3E+3
Sc-48	6E-07	2E-07	1E+4	8E+2	1E+3
Sc-49[38]	2E-05	8E-06	3E+5	2E+4	5E+4
Ti-44	2E-09	7E-09	2E+2	3E+2	6
Ti-45	1E-05	2E-06	1E+5	9E+3	3E+4
V-47[38]	3E-05	6E-06	2E+5	3E+4	8E+4
V-48	3E-07	2E-07	7E+3	6E+2	6E+2
V-49	8E-06	1E-05	7E+5	7E+4	2E+4
Cr-48	3E-06	2E-06	8E+4	6E+3	7E+3
Cr-49[38]	4E-05	5E-06	2E+5	3E+4	8E+4
Cr-51	8E-06	1E-05	5E+5	4E+4	2E+4
Mn-51[38]	2E-05	7E-06	2E+5	2E+4	5E+4
Mn-52m[38]	4E-05	5E-06	2E+5	3E+4	9E+4
Mn-52	4E-07	2E-07	8E+3	7E+2	9E+2
Mn-53	5E-06	1E-05	2E+5	5E+4	1E+4
Mn-54	3E-07	4E-07	1E+4	2E+3	8E+2
Mn-56	6E-06	2E-06	8E+4	5E+3	2E+4
Fe-52	1E-06	5E-07	2E+4	9E+2	2E+3
Fe-55	8E-07	6E-07	2E+4	9E+3	2E+3

	10CFR20 DAC uCi/mL	10CFR835 DAC uCi/mL	10CFR835 DAC Bq/M^3	10CFR20 ALIs uCi Ingestion	10CFR20 ALIs uCi Inhalation
Fe-59	1E-07	1E-07	6E+3	8E+2	3E+2
Fe-60	3E-09	1E-09	60	30	6
Co-55	1E-06	5E-07	2E+4	1E+3	3E+3
Co-56	8E-08	1E-07	4E+3	4E+2	2E+2
Co-57	3E-07	9E-07	3E+4	4E+3	7E+2
Co-58m	3E-05	3E-05	1E+6	6E+4	6E+4
Co-58	3E-07	3E-07	1E+4	1E+3	7E+2
Co-60m[38]	1E-03	4E-04	1E+7	1E+6	3E+6
Co-60	1E-08	3E-08	1E+3	2E+2	30
Co-61[38]	2E-05	6E-06	2E+5	2E+4	6E+4
Co-62m[38]	6E-05	6E-06	2E+5	4E+4	2E+5
Ni-56	5E-07	X	X	1E+3	1E+3
Ni-56[11]	X	4E-07	1E+4	X	X
Ni-56[12]	X	4E-07	1E+4	X	X
Ni-57	1E-06	X	X	2E+3	3E+3
Ni-57[11]	X	5E-07	2E+4	X	X
Ni-57[12]	X	7E-07	2E+4	X	X
Ni-59	8E-07	X	X	2E+4	2E+3
Ni-59[11]	X	2E-06	9E+4	X	X
Ni-59[12]	X	6E-07	2E+4	X	X
Ni-63	3E-07	X	X	9E+3	2E+3
Ni-63[11]	X	1E-06	4E+4	X	X
Ni-63[12]	X	2E-07	1E+4	X	X
Ni-65	7E-06	X	X	8E+3	2E+4
Ni-65[11]	X	4E-06	1E+5	X	X
Ni-65[12]	X	8E-07	3E+4	X	X
Ni-66	3E-07	X	X	4E+2	6E+2
Ni-66[11]	X	2E-07	1E+4	X	X
Ni-66[12]	X	2E-07	1E+4	X	X
Cu-60[38]	4E-05	4E-06	1E+5	3E+4	9E+4

	10CFR20 DAC uCi/mL	10CFR835 DAC uCi/mL	Bq/M^3	10CFR20 ALIs uCi Ingestion	Inhalation
Cu-61	1E-05	3E-06	1E+5	1E+4	3E+4
Cu-64	9E-06	3E-06	1E+5	1E+4	2E+4
Cu-67	2E-06	2E-06	3E+4	5E+3	5E+3
Zn-62	1E-06	9E-07	3E+4	1E+3	3E+3
Zn-63[38]	3E-05	8E-07	2E+5	2E+4	7E+4
Zn-65	1E-07	5E-06	7E+3	4E+2	3E+2
Zn-69m	3E-06	2E-07	6E+4	4E+3	7E+3
Zn-69[38]	6E-05	1E-06	2E+5	6E+4	1E+5
Zn-71m	7E-06	7E-06	5E+4	6E+3	2E+4
Zn-72	5E-07	1E-06	1E+4	1E+3	1E+3
Ga-65[38]	7E-05	3E-07	3E+5	5E+4	2E+5
Ga-66	1E-06	7E-07	2E+4	1E+3	3E+3
Ga-67	4E-06	2E-06	7E+4	7E+3	1E+4
Ga-68[38]	2E-05	4E-06	1E+5	2E+4	4E+4
Ga-70[38]	7E-05	1E-05	4E+5	5E+4	2E+5
Ga-72	1E-06	5E-07	2E+4	1E+3	3E+3
Ga-73	6E-06	2E-06	1E+5	5E+3	2E+4
Ge-66	8E-06	2E-06	9E+4	2E+4	2E+4
Ge-67[38]	4E-05	7E-06	2E+5	3E+4	9E+4
Ge-68	4E-08	7E-08	2E+3	5E+3	1E+2
Ge-69	3E-06	1E-06	3E+4	1E+4	8E+3
Ge-71	2E-05	5E-05	1E+6	5E+5	4E+4
Ge-75[38]	3E-05	7E-06	2E+5	4E+4	8E+4
Ge-77	2E-06	1E-06	4E+4	9E+3	6E+3
Ge-78[38]	9E-06	3E-06	1E+5	2E+4	2E+4
As-69[38]	5E-05	9E-06	3E+5	3E+4	1E+5
As-70[38]	2E-05	2E-06	8E+4	1E+4	5E+4
As-71	2E-06	1E-06	4E+4	4E+3	5E+3
As-72	6E-07	4E-07	1E+4	9E+2	1E+3
As-73	7E-07	8E-07	3E+4	8E+3	2E+3

	10CFR20 DAC	10CFR835 DAC		10CFR20 ALIs uCi	
	uCi/mL	uCi/mL	Bq/M^3	Ingestion	Inhalation
As-74	3E-07	3E-07	1E+4	1E+3	8E+2
As-76	6E-07	6E-07	2E+4	1E+3	1E+3
As-77	2E-06	1E-06	4E+4	4E+3	5E+3
As-78[38]	9E-06	3E-06	1E+5	8E+3	2E+4
Se-70[38]	2E-05	2E-06	9E+4	1E+4	4E+4
Se-73m[38]	6E-05	1E-05	4E+5	3E+4	1E+5
Se-73	5E-06	1E-06	5E+4	3E+3	1E+4
Se-75	3E-07	3E-07	1E+4	5E+2	6E+2
Se-79	2E-07	1E-07	6E+3	6E+2	6E+2
Se-81m[38]	3E-05	6E-06	2E+5	2E+4	7E+4
Se-81[38]	9E-05	1E-05	4E+5	6E+4	2E+5
Se-83[38]	5E-05	5E-06	1E+5	3E+4	1E+5
Br-74m[38]	2E-05	2E-06	1E+5	1E+4	4E+4
Br-74[38]	3E-05	4E-06	1E+5	2E+4	7E+4
Br-75[38]	2E-05	3E-06	1E+5	3E+4	5E+4
Br-76	2E-06	5E-07	2E+4	4E+3	4E+3
Br-77	8E-06	2E-06	7E+4	2E+4	2E+4
Br-80m	6E-06	5E-06	2E+5	2E+4	1E+4
Br-80[38]	8E-05	2E-05	7E+5	5E+4	2E+5
Br-82	2E-06	3E-07	1E+4	3E+3	4E+3
Br-83	3E-05	6E-06	2E+5	5E+4	6E+4
Br-84[38]	2E-05	5E-06	2E+5	2E+4	6E+4
Rb-79[38]	5E-05	8E-06	2E+5	4E+4	1E+5
Rb-81m[38]	1E-04	1E-05	6E+5	2E+5	3E+5
Rb-81	2E-05	2E-06	1E+5	4E+4	5E+4
Rb-82m	7E-06	8E-07	3E+4	1E+4	2E+4
Rb-83	4E-07	5E-07	2E+4	6E+2	1E+3
Rb-84	3E-07	3E-07	1E+4	5E+2	8E+2
Rb-86	3E-07	4E-07	1E+4	5E+2	8E+2
Rb-87	6E-07	7E-07	2E+4	1E+3	2E+3

	10CFR20 DAC	10CFR835 DAC		10CFR20 ALIs uCi	
	uCi/mL	uCi/mL	Bq/M^3	Ingestion	Inhalation
Rb-88[38]	3E-05	1E-05	5E+5	2E+4	6E+4
Rb-89[38]	6E-05	1E-05	3E+5	4E+4	1E+5
Sr-80[38]	5E-06	2E-06	9E+4	4E+3	1E+4
Sr-81[38]	3E-05	5E-06	2E+5	2E+4	8E+4
Sr-82	4E-08	7E-08	2E+3	2E+2	90
Sr-83	1E-06	9E-07	3E+4	2E+3	4E+3
Sr-85m[38]	3E-04	3E-05	1E+6	2E+5	6E+5
Sr-85	6E-07	8E-07	3E+4	3E+3	2E+3
Sr-87m	5E-05	9E-06	3E+5	4E+4	1E+5
Sr-89	6E-08	1E-07	3E+3	5E+2	1E+2
Sr-90	2E-09	7E-09	2E+2	30	4
Sr-91	1E-06	9E-07	3E+4	2E+3	4E+3
Sr-92	3E-06	1E-06	6E+4	3E+3	7E+3
Y-86m[38]	2E-05	6E-06	2E+5	2E+4	5E+4
Y-86	1E-06	4E-07	1E+4	1E+3	3E+3
Y-87	1E-06	8E-07	3E+4	2E+3	3E+3
Y-88	1E-07	1E-07	6E+3	1E+3	2E+2
Y-90m	5E-06	4E-06	1E+5	8E+3	1E+4
Y-90	3E-07	3E-07	1E+4	4E+2	6E+2
Y-91m[38]	7E-05	2E-05	7E+5	1E+5	2E+5
Y-91	5E-08	9E-08	3E+3	5E+2	1E+2
Y-92	3E-06	2E-06	7E+4	3E+3	8E+3
Y-93	1E-06	9E-07	3E+4	1E+3	2E+3
Y-94[38]	3E-05	8E-06	3E+5	2E+4	8E+4
Y-95[38]	6E-05	1E-05	4E+5	4E+4	1E+5
Zr-86	1E-06	5E-07	2E+4	1E+3	2E+3
Zr-88	9E-08	1E-07	5E+3	4E+3	2E+2
Zr-89	1E-06	6E-07	2E+4	2E+3	2E+3
Zr-93	3E-09	3E-09	1E+2	1E+3	6
Zr-95	5E-08	9E-08	3E+3	1E+3	1E+2

	10CFR20 DAC	10CFR835 DAC		10CFR20 ALIs uCi	
	uCi/mL	uCi/mL	Bq/M^3	Ingestion	Inhalation
Zr-97	5E-07	4E-07	1E+4	6E+2	1E+3
Nb-88[38]	9E-05	5E-06	1E+5	5E+4	2E+5
Nb-89m[13]	2E-05	3E-06	1E+5	1E+4	4E+4
Nb-89[14]	6E-06	2E-06	1E+5	5E+3	2E+4
Nb-90	1E-06	3E-07	1E+4	1E+3	2E+3
Nb-93m	7E-08	6E-07	2E+4	9E+3	2E+2
Nb-94	6E-09	2E-08	8E+2	9E+2	20
Nb-95m	9E-07	6E-07	2E+4	2E+3	2E+3
Nb-95	5E-07	4E-07	1E+4	2E+3	1E+3
Nb-96	1E-06	4E-07	1E+4	1E+3	2E+3
Nb-97[38]	3E-05	5E-06	1E+5	2E+4	7E+4
Nb-98[38]	2E-05	3E-06	1E+5	1E+4	5E+4
Mo-90	2E-06	7E-07	2E+4	2E+3	5E+3
Mo-93m	6E-06	1E-06	3E+4	4E+3	1E+4
Mo-93	8E-08	2E-07	7E+3	2E+4	2E+2
Mo-99	6E-07	5E-07	1E+4	1E+3	1E+3
Mo-101[38]	6E-05	6E-06	2E+5	4E+4	1E+5
Tc-93m[38]	6E-05	7E-06	2E+5	3E+4	2E+5
Tc-93	3E-05	3E-06	1E+5	3E+4	7E+4
Tc-94m[38]	2E-05	4E-06	1E+5	2E+4	4E+4
Tc-94	8E-06	1E-06	3E+4	9E+3	2E+4
Tc-95m	8E-07	6E-07	2E+4	4E+3	2E+3
Tc-95	8E-06	1E-06	5E+4	1E+4	2E+4
Tc-96m[38]	1E-04	2E-05	1E+6	2E+5	2E+5
Tc-96	9E-07	3E-07	1E+4	2E+3	2E+3
Tc-97m	5E-07	2E-07	7E+3	5E+3	1E+3
Tc-97	2E-06	3E-06	1E+5	4E+4	6E+3
Tc-98	1E-07	9E-08	3E+3	1E+3	3E+2
Tc-99m	6E-05	1E-05	4E+5	8E+4	2E+5
Tc-99	3E-07	1E-07	6E+3	4E+3	7E+2

	10CFR20 DAC	10CFR835 DAC		10CFR20 ALIs uCi	
	uCi/mL	uCi/mL	Bq/M^3	Ingestion	Inhalation
Tc-101[38]	1E-04	1E-05	4E+5	9E+4	3E+5
Tc-104[38]	3E-05	7E-06	2E+5	2E+4	7E+4
Ru-94[38]	2E-05	5E-06	1E+5	2E+4	4E+4
Ru-97	5E-06	2E-06	8E+4	8E+3	1E+4
Ru-103	3E-07	2E-07	9E+3	2E+3	6E+2
Ru-105	5E-06	2E-06	8E+4	5E+3	1E+4
Ru-106	5E-09	1E-08	5E+2	2E+2	10
Rh-99m	2E-05	3E-06	1E+5	2E+4	6E+4
Rh-99	8E-07	6E-07	2E+4	2E+3	2E+3
Rh-100	2E-06	5E-07	1E+4	2E+3	4E+3
Rh-101m	3E-06	1E-06	6E+4	6E+3	8E+3
Rh-101	6E-08	1E-07	6E+3	2E+3	2E+2
Rh-102m	5E-08	1E-07	4E+3	1E+3	1E+2
Rh-102	2E-08	6E-08	2E+3	6E+2	60
Rh-103m[38]	5E-04	2E-04	8E+6	4E+5	1E+6
Rh-105	2E-06	1E-06	4E+4	4E+3	6E+3
Rh-106m	1E-05	1E-06	5E+4	8E+3	3E+4
Rh-107[38]	1E-04	9E-06	3E+5	7E+4	2E+5
Pd-100	5E-07	5E-07	2E+4	1E+3	1E+3
Pd-101	1E-05	3E-06	1E+5	1E+4	3E+4
Pd-103	1E-06	1E-06	6E+4	6E+3	4E+3
Pd-107	2E-07	1E-06	7E+4	3E+4	4E+2
Pd-109	2E-06	1E-06	4E+4	2E+3	5E+3
Ag-102[38]	8E-05	7E-06	2E+5	5E+4	2E+5
Ag-103[38]	4E-05	7E-06	2E+5	4E+4	1E+5
Ag-104m[38]	4E-05	6E-06	2E+5	3E+4	9E+4
Ag-104[38]	3E-05	3E-06	1E+5	2E+4	7E+4
Ag-105	4E-07	7E-07	2E+4	3E+3	1E+3
Ag-106m	3E-07	2E-07	9E+3	8E+2	7E+2
Ag-106[38]	8E-05	1E-05	4E+5	6E+4	2E+5

	10CFR20 DAC uCi/mL	10CFR835 DAC uCi/mL	Bq/M^3	10CFR20 ALIs uCi Ingestion	Inhalation
Ag-108m	1E-08	2E-08	1E+3	6E+2	20
Ag-110m	4E-08	7E-08	2E+3	5E+2	90
Ag-111	4E-07	3E-07	1E+4	9E+2	9E+2
Ag-112	3E-06	2E-06	8E+4	3E+3	8E+3
Ag-115[38]	3E-05	8E-06	3E+5	3E+4	8E+4
Cd-104[38]	3E-05	4E-06	1E+5	2E+4	7E+4
Cd-107	2E-05	4E-06	1E+5	2E+4	5E+4
Cd-109	1E-08	1E-07	9E+2	3E+2	50
Cd-113m	1E-09	1E-09	60	20	2
Cd-113	9E-10	1E-09	50	20	2
Cd-115m	2E-08	3E-08	1E+3	3E+2	50
Cd-115	5E-07	4E-07	1E+4	9E+2	1E+3
Cd-117m	5E-06	1E-06	4E+4	5E+3	1E+4
Cd-117	5E-06	2E-06	7E+4	5E+3	1E+4
In-109	2E-05	4E-06	1E+5	2E+4	4E+4
In-110[15, 38]	2E-05	4E-06	1E+5	2E+4	4E+4
In-110[16]	7E-06	9E-07	3E+4	5E+3	2E+4
In-111	3E-06	1E-06	5E+4	4E+3	6E+3
In-112	3E-04	1E-05	6E+5	2E+5	6E+5
In-113m[38]	6E-05	1E-05	3E+5	5E+4	1E+5
In-114m	3E-08	5E-08	1E+3	3E+2	60
In-115m	2E-05	6E-06	2E+5	1E+4	4E+4
In-115	6E-10	1E-09	40	40	10
In-116m[38]	3E-05	4E-06	1E+5	2E+4	8E+4
In-117m[38]	1E-05	5E-06	1E+5	1E+4	3E+4
In-117[38]	7E-05	5E-06	2E+5	6E+4	2E+5
In-119m[38]	5E-05	1E-05	4E+5	4E+4	1E+5
Sn-110	5E-06	1E-06	6E+4	4E+3	1E+4
Sn-111[38]	9E-05	1E-05	5E+5	7E+4	2E+5
Sn-113	2E-07	2E-07	1E+4	2E+3	5E+2

	10CFR20 DAC	10CFR835 DAC		10CFR20 ALIs uCi	
	uCi/mL	uCi/mL	Bq/M^3	Ingestion	Inhalation
Sn-117m	5E-07	2E-07	9E+3	2E+3	1E+3
Sn-119m	4E-07	3E-07	1E+4	3E+3	1E+3
Sn-121m	2E-07	1E-07	6E+3	3E+3	5E+2
Sn-121	5E-06	2E-06	7E+4	6E+3	1E+4
Sn-123m[38]	5E-05	7E-06	2E+5	5E+4	1E+5
Sn-123	7E-08	1E-07	3E+3	5E+2	2E+2
Sn-125	1E-07	2E-07	7E+3	4E+2	4E+2
Sn-126	2E-08	3E-08	1E+3	3E+2	60
Sn-127	8E-06	2E-06	7E+4	7E+3	2E+4
Sn-128[38]	1E-05	2E-06	8E+4	9E+3	3E+4
Sb-115[38]	1E-04	1E-05	4E+5	8E+4	2E+5
Sb-116m[38]	3E-05	2E-06	1E+5	2E+4	7E+4
Sb-116[38]	1E-04	1E-05	3E+5	7E+4	3E+5
Sb-117	9E-05	1E-05	3E+5	7E+4	2E+5
Sb-118m	8E-06	1E-06	4E+4	5E+3	2E+4
Sb-119	1E-05	6E-06	2E+5	2E+4	3E+4
Sb-120[17]	2E-04	2E-05	7E+5	1E+5	4E+5
Sb-120[18]	5E-07	3E-07	1E+4	9E+2	1E+3
Sb-122	4E-07	4E-07	1E+4	7E+2	1E+3
Sb-124m[38]	2E-04	3E-05	1E+6	2E+5	6E+5
Sb-124	1E-07	1E-07	4E+3	5E+2	2E+2
Sb-125	2E-07	1E-07	6E+3	2E+3	5E+2
Sb-126m[38]	8E-05	7E-06	2E+5	5E+4	2E+5
Sb-126	2E-07	1E-07	6E+3	5E+2	5E+2
Sb-127	4E-07	3E-07	1E+4	7E+2	9E+2
Sb-128[19]	1E-06	5E-07	2E+4	8E+4	4E+5
Sb-128[20]	2E-04	9E-06	3E+5	1E+3	3E+3
Sb-129	4E-06	1E-06	5E+4	3E+3	9E+3
Sb-130[38]	3E-05	2E-06	1E+5	2E+4	6E+4
Sb-131[38]	1E-05	4E-06	1E+5	1E+4	2E+4

	10CFR20 DAC	10CFR835 DAC		10CFR20 ALIs uCi	
	uCi/mL	uCi/mL	Bq/M^3	Ingestion	Inhalation
Te-116	9E-06	2E-06	7E+4	8E+3	2E+4
Te-116[10]	X	6E-06	1E+3	X	X
Te-121m	8E-08	1E-07	4E+3	5E+2	2E+2
Te-121m[10]	X	4E-08	1E+3	X	X
Te-121	1E-06	1E-06	4E+4	3E+3	3E+3
Te-121[10]	X	1E-06	3E+4	X	X
Te-123m	9E-08	1E-07	4E+3	6E+2	2E+2
Te-123m[10]	X	5E-08	2E+3	X	X
Te-123	8E-08	2E-08	1E+3	5E+2	2E+2
Te-123[10]	X	1E-08	4E+2	X	X
Te-125m	2E-07	1E-07	7E+3	1E+3	4E+2
Te-125m[10]	X	1E-07	3E+3	X	X
Te-127m	1E-07	9E-08	3E+3	6E+2	3E+2
Te-127m[10]	X	6E-08	2E+3	X	X
Te-127	7E-06	3E-06	1E+5	7E+3	2E+4
Te-127[10]	X	7E-06	2E+5	X	X
Te-129m	1E-07	1E-07	3E+3	5E+2	2E+2
Te-129m[10]	X	1E-07	5E+3	X	X
Te-129[38]	3E-05	7E-06	2E+5	3E+4	6E+4
Te-129[10]	X	1E-05	5E+5	X	X
Te-131m	2E-07	3E-07	1E+4	3E+2	4E+2
Te-131m[10]	X	1E-07	5E+3	X	X
Te-131[38]	2E-06	7E-06	2E+5	3E+3	5E+3
Te-131[10]	X	6E-06	2E+5	X	X
Te-132	9E-08	1E-07	6E+3	2E+2	2E+2
Te-132[10]	X	7E-08	2E+3	X	X
Te-133m[10]	X	1E-06	6E+4	X	X
Te-133m[38]	2E-06	2E-06	1E+5	3E+3	5E+3
Te-133[38]	9E-06	9E-06	3E+5	1E+4	2E+4
Te-133[10]	X	7E-06	2E+5	X	X

	10CFR20 DAC uCi/mL	10CFR835 DAC uCi/mL	Bq/M^3	10CFR20 ALIs uCi Ingestion	Inhalation
Te-134[10]	X	6E-06	2E+5	X	X
Te-134[38]	1E-05	2E-06	1E+5	2E+4	2E+4
I-120m[38]	9E-06	2E-06	1E+5	1E+4	2E+4
I-120m[10]	X	3E-06	5E+4	X	X
I-120m[21]	X	4E-06	8E+4	X	X
I-120[38]	4E-06	2E-06	6E+4	4E+3	9E+3
I-120[10]	X	1E-06	5E+4	X	X
I-120[21]	X	1E-06	1E+5	X	X
I-121	8E-06	8E-06	3E+5	1E+4	2E+4
I-121[10]	X	4E-06	1E+5	X	X
I-121[21]	X	5E-06	2E+5	X	X
I-123	3E-06	2E-06	1E+5	3E+3	6E+3
I-123[10]	X	1E-06	5E+4	X	X
I-123[21]	X	1E-06	7E+4	X	X
I-124	3E-08	4E-08	1E+3	50	80
I-124[10]	X	2E-08	9E+2	X	X
I-124[21]	X	3E-08	1E+3	X	X
I-125	3E-08	3E-08	1E+3	40	60
I-125[10]	X	2E-08	7E+2	X	X
I-125[21]	X	2E-08	9E+2	X	X
I-126	1E-08	2E-08	7E+2	20	40
I-126[10]	X	1E-08	4E+2	X	X
I-126[21]	X	1E-08	5E+2	X	X
I-128	5E-05	1E-05	6E+5	4E+4	1E+5
I-128[10]	X	8E-06	3E+5	X	X
I-128[21]	X	3E-05	1E+6	X	X
I-129	4E-09	5E-09	2E+2	50	90
I-129[10]	X	2E-09	1E+2	X	X
I-129[21]	X	3E-09	1E+2	X	X
I-130	3E-07	3E-07	1E+4	4E+2	7E+2

	10CFR20 DAC	10CFR835 DAC		10CFR20 ALIs uCi	
	uCi/mL	uCi/mL	Bq/M^3	Ingestion	Inhalation
I-130[10]	X	1E-07	6E+3	X	X
I-130[21]	X	2E-07	7E+3	X	X
I-131	2E-08	2E-08	9E+2	30	50
I-131[10]	X	1E-08	5E+2	X	X
I-131[21]	X	1E-08	6E+2	X	X
I-132m[38]	4E-06	3E-06	1E+5	4E+3	8E+3
I-132m[10]	X	1E-06	6E+4	X	X
I-132m[21]	X	1E-06	7E+4	X	X
I-132	3E-06	2E-06	7E+4	4E+3	8E+3
I-132[10]	X	1E-06	5E+4	X	X
I-132[21]	X	1E-06	6E+4	X	X
I-133	1E-07	1E-07	5E+3	1E+2	3E+2
I-133[10]	X	7E-08	2E+3	X	X
I-133[21]	X	9E-08	3E+3	X	X
I-134[38]	2E-05	3E-06	1E+5	2E+4	5E+4
I-134[10]	X	3E-06	1E+5	X	X
I-134[21]	X	8E-06	2E+5	X	X
I-135	7E-07	6E-07	2E+4	8E+2	2E+3
I-135[10]	X	3E-07	1E+4	X	X
I-135[21]	X	4E-07	1E+4	X	X
Cs-125[38]	6E-05	1E-05	4E+5	5E+4	1E+5
Cs-127	4E-05	4E-06	1E+5	6E+4	9E+4
Cs-129	1E-05	2E-06	9E+4	2E+4	3E+4
Cs-130[38]	8E-05	1E-05	6E+5	6E+4	2E+5
Cs-131	1E-05	7E-06	2E+5	2E+4	3E+4
Cs-132	2E-06	9E-07	3E+4	3E+3	4E+3
Cs-134m	6E-05	8E-06	2E+5	1E+5	1E+5
Cs-134	4E-08	5E-08	2E+3	70	1E+2
Cs-135m[38]	8E-05	8E-06	2E+5	1E+5	2E+5
Cs-135	5E-07	5E-07	2E+4	7E+2	1E+3

	10CFR20 DAC uCi/mL	10CFR835 DAC uCi/mL	Bq/M³	10CFR20 ALIs uCi Ingestion	Inhalation
Cs-136	3E-07	2E-07	1E+4	4E+2	7E+2
Cs-137	6E-08	8E-08	3E+3	1E+2	2E+2
Cs-138[38]	2E-05	5E-06	2E+5	2E+4	6E+4
Ba-126[38]	6E-06	4E-06	1E+5	6E+3	2E+4
Ba-128	7E-07	4E-07	1E+4	5E+2	2E+3
Ba-131m	6E-04	4E-05	1E+6	4E+5	1E+6
Ba-131	3E-06	1E-06	4E+4	3E+3	8E+3
Ba-133m	4E-06	2E-06	7E+4	2E+3	9E+3
Ba-133	3E-07	3E-07	1E+4	2E+3	7E+2
Ba-135m	5E-06	2E-06	9E+4	3E+3	1E+4
Ba-139[38]	1E-05	1E-05	3E+5	1E+4	3E+4
Ba-140	6E-07	3E-07	1E+4	5E+2	1E+3
Ba-141[38]	3E-05	1E-05	4E+5	2E+4	7E+4
Ba-142[38]	6E-05	9E-06	3E+5	5E+4	1E+5
La-131[38]	5E-05	8E-06	3E+5	5E+4	1E+5
La-132	4E-06	1E-06	5E+4	3E+3	1E+4
La-135	4E-05	1E-05	4E+5	4E+4	9E+4
La-137	3E-08	4E-08	1E+3	1E+4	60
La-138	1E-09	3E-09	1E+2	9E+2	4
La-140	5E-07	3E-07	1E+4	6E+2	1E+3
La-141	4E-06	2E-06	9E+4	4E+3	9E+3
La-142[38]	9E-06	2E-06	8E+4	8E+3	2E+4
La-143[38]	4E-05	1E-05	4E+5	4E+4	9E+4
Ce-134	3E-07	3E-07	1E+4	5E+2	7E+2
Ce-135	2E-06	5E-07	2E+4	2E+3	4E+3
Ce-137m	2E-06	9E-07	3E+4	2E+3	4E+3
Ce-137	5E-05	1E-05	7E+5	5E+4	1E+5
Ce-139	3E-07	4E-07	1E+4	5E+3	7E+2
Ce-141	2E-07	1E-07	6E+3	2E+3	6E+2
Ce-143	7E-07	5E-07	2E+4	1E+3	2E+3

	10CFR20 DAC uCi/mL	10CFR835 DAC uCi/mL	10CFR835 DAC Bq/M^3	10CFR20 ALIs uCi Ingestion	10CFR20 ALIs uCi Inhalation
Ce-144	6E-09	1E-08	7E+2	2E+2	10
Pr-136[38]	9E-05	1E-05	3E+5	5E+4	2E+5
Pr-137[38]	6E-05	9E-06	3E+5	4E4	1E+5
Pr-138m	2E-05	2E-06	7E+4	1E+4	4E+4
Pr-139	5E-05	1E-05	2E+5	4E+4	1E+5
Pr-142m[38]	6E-05	5E-05	2E+6	8E+4	1E+5
Pr-142	8E-07	7E-07	2E+4	1E+3	2E+3
Pr-143	3E-07	2E-07	9E+3	9E+2	7E+2
Pr-144[38]	5E-05	1E-05	4E+5	3E+4	1E+5
Pr-145	3E-06	2E-06	8E+4	3E+3	8E+3
Pr-147[38]	8E-05	9E-06	3E+5	5E+4	2E+5
Nd-136[38]	2E-05	4E-06	1E+5	1E+4	5E+4
Nd-138	2E-06	1E-06	5E+4	2E+3	5E+3
Nd-139m	6E-06	1E-06	5E+4	5E+3	1E+4
Nd-139[38]	1E-04	1E-05	6E+5	9E+4	3E+5
Nd-141	3E-04	3E-05	1E+6	2E+5	6E+5
Nd-147	4E-07	2E-07	9E+3	1E+3	8E+2
Nd-149[38]	1E-05	4E-06	1E+5	1E+4	2E+4
Nd-151[38]	8E-05	9E-06	3E+5	7E+4	2E+5
Pm-141[38]	7E-05	1E-05	4E+5	5E+4	2E+5
Pm-143	2E-07	5E-07	2E+4	5E+3	6E+2
Pm-144	5E-08	1E-07	3E+3	1E+3	1E+2
Pm-145	7E-08	1E-07	1E+4	1E+4	2E+2
Pm-146	2E-08	4E-08	1E+3	2E+3	40
Pm-147	5E-08	1E-07	4E+3	4E+3	1E+2
Pm-148m	1E-07	1E-07	4E+3	7E+2	3E+2
Pm-148	2E-07	2E-07	9E+3	4E+2	5E+2
Pm-149	8E-07	6E-07	2E+4	1E+3	2E+3
Pm-150	7E-06	2E-06	8E+4	5E+3	2E+4
Pm-151	1E-06	8E-07	3E+4	2E+3	3E+3

	10CFR20 DAC	10CFR835 DAC		10CFR20 ALIs uCi	
	uCi/mL	uCi/mL	Bq/M^3	Ingestion	Inhalation
Sm-141m[38]	4E-05	5E-06	2E+5	3E+4	1E+5
Sm-141[38]	8E-05	1E-05	4E+5	5E+4	2E+5
Sm-142[38]	1E-05	4E-06	1E+5	8E+3	3E+4
Sm-145	2E-07	4E-07	1E+4	6E+3	5E+2
Sm-146	1E-11	2E-11	1	10	4E-2
Sm-147	2E-11	2E-11	1	20	4E-2
Sm-151	4E-08	7E-08	2E+3	1E+4	1E+2
Sm-153	1E-06	8E-07	3E+4	2E+3	3E+3
Sm-155[38]	9E-05	1E-05	3E+5	6E+4	2E+5
Sm-156	4E-06	2E-06	7E+4	5E+3	9E+3
Eu-145	8E-07	5E-07	2E+4	2E+3	2E+3
Eu-146	5E-07	3E-07	1E+4	1E+3	1E+3
Eu-147	7E-07	5E-07	2E+4	3E+3	2E+3
Eu-148	1E-07	2E-07	9E+3	1E+3	4E+2
Eu-149	1E-06	2E-06	9E+4	1E+4	3E+3
Eu-150[22]	4E-06	2E-06	7E+4	3E+3	8E+3
Eu-150[23]	8E-09	1E-08	6E+2	8E+2	20
Eu-152m	3E-06	1E-06	6E+4	3E+3	6E+3
Eu-152	1E-08	2E-08	7E+2	8E+2	20
Eu-154	8E-09	1E-08	5E+2	5E+2	20
Eu-155	4E-08	7E-08	2E+3	4E+3	90
Eu-156	2E-07	1E-07	6E+3	6E+2	5E+2
Eu-157	2E-06	1E-06	4E+4	2E+3	5E+3
Eu-158[38]	2E-05	5E-06	1E+5	2E+4	6E+4
Gd-145[38]	6E-05	7E-06	2E+5	5E+4	2E+5
Gd-146	5E-08	1E-07	4E+3	1E+3	1E+2
Gd-147	1E-06	6E-07	2E+4	2E+3	4E+3
Gd-148	3E-12	5E-12	0.2	10	8E-3
Gd-149	9E-07	7E-07	2E+4	3E+3	2E+3
Gd-151	2E-07	2E-07	9E+3	6E+3	4E+2

	10CFR20 DAC	10CFR835 DAC		10CFR20 ALIs uCi	
	uCi/mL	uCi/mL	Bq/M^3	Ingestion	Inhalation
Gd-152	4E-12	7E-12	0.2	20	1E-2
Gd-153	6E-08	9E-08	3E+3	5E+3	1E+2
Gd-159	2E-06	1E-06	5E+4	3E+3	6E+3
Tb-147[38]	1E-05	2E-06	1E+5	9E+3	3E+4
Tb-149	3E-07	1E-07	6E+3	5E+3	7E+2
Tb-150	9E-06	2E-06	8E+4	5E+3	2E+4
Tb-151	4E-06	1E-06	4E+4	4E+3	9E+3
Tb-153	3E-06	2E-06	8E+4	5E+3	7E+3
Tb-154	2E-06	5E-07	2E+4	2E+3	4E+3
Tb-155	3E-06	2E-06	8E+4	6E+3	8E+3
Tb-156m[24]	3E-06	2E-06	9E+4	2E+4	3E+4
Tb-156m[25]	1E-05	4E-06	1E+5	7E+3	8E+3
Tb-156	6E-07	4E-07	1E+4	1E+3	1E+3
Tb-157	1E-07	2E-07	8E+3	5E+4	3E+2
Tb-158	8E-09	1E-08	6E+2	1E+3	20
Tb-160	9E-08	1E-07	3E+3	7E+2	2E+2
Tb-161	7E-07	4E-07	1E+4	2E+3	2E+3
Dy-155	1E-05	2E-06	1E+5	9E+3	3E+4
Dy-157	3E-05	5E-06	1E+5	2E+4	6E+4
Dy-159	1E-06	2E-06	8E+4	1E+4	2E+3
Dy-165	2E-05	6E-06	2E+5	1E+4	5E+4
Dy-166	3E-07	3E-07	1E+4	6E+2	7E+2
Ho-155[38]	6E-05	1E-05	4E+5	4E+4	2E+5
Ho-157[38]	6E-04	2E-05	1E+6	3E+5	1E+6
Ho-159[38]	4E-04	2E-05	9E+5	2E+5	1E+6
Ho-161	2E-04	3E-05	1E+6	1E+5	4E+5
Ho-162m[38]	1E-04	9E-06	3E+5	5E+4	3E+5
Ho-162[38]	1E-03	5E-05	2E+6	5E+5	2E+6
Ho-164m[38]	1E-04	3E-05	1E+6	1E+5	3E+5
Ho-164[38]	3E-04	2E-05	8E+5	2E+5	6E+5

	10CFR20 DAC	10CFR835 DAC		10CFR20 ALIs uCi	
	uCi/mL	uCi/mL	Bq/M^3	Ingestion	Inhalation
Ho-166m	3E-09	7E-09	2E+2	6E+2	70
Ho-166	7E-07	6E-07	2E+4	9E+2	2E+3
Ho-167	2E-05	4E-06	1E+5	2E+4	6E+4
Er-161	3E-05	3E-06	1E+5	2E+4	6E+4
Er-165	8E-05	2E-05	1E+6	6E+4	2E+5
Er-169	1E-06	6E-07	2E+4	3E+3	3E+3
Er-171	4E-06	1E-06	6E+4	4E+3	1E+4
Er-172	6E-07	4E-07	1E+4	1E+3	1E+3
Tm-162[38]	1E-04	9E-06	3E+5	7E+4	3E+5
Tm-166	6E-06	1E-06	4E+4	4E+3	1E+4
Tm-167	8E-07	5E-07	2E+4	2E+3	2E+3
Tm-170	9E-08	1E-07	4E+3	8E+2	2E+2
Tm-171	1E-07	2E-07	9E+3	1E+4	3E+2
Tm-172	5E-07	4E-07	1E+4	7E+2	1E+3
Tm-173	5E-06	2E-06	8E+4	4E+3	1E+4
Tm-175[38]	1E-04	8E-06	2E+5	7E+4	3E+5
Yb-162[38]	1E-04	1E-05	5E+5	7E+4	3E+5
Yb-166	8E-07	5E-07	2E+4	1E+3	3E+3
Yb-167[38]	3E-04	3E-05	1E+6	3E+5	7E+5
Yb-169	3E-07	2E-07	8E+3	2E+3	7E+2
Yb-175	1E-06	8E-07	2E+4	3E+3	3E+3
Yb-177[38]	2E-05	5E-06	2E+5	2E+4	5E+4
Yb-178[38]	2E-05	5E-06	1E+5	1E+4	4E+4
Lu-169	2E-06	9E-07	3E+4	3E+3	4E+3
Lu-170	8E-07	4E-07	1E+4	1E+3	2E+3
Lu-171	8E-07	6E-07	2E+4	2E+3	2E+3
Lu-172	5E-07	3E-07	1E+4	1E+3	1E+3
Lu-173	1E-07	2E-07	8E+3	5E+3	3E+2
Lu-174m	9E-08	2E-07	7E+3	2E+3	2E+2
Lu-174	5E-08	9E-08	3E+3	5E+3	1E+2

	10CFR20 DAC uCi/mL	10CFR835 DAC uCi/mL	Bq/M^3	10CFR20 ALIs uCi Ingestion	Inhalation
Lu-176m	9E-06	3E-06	1E+5	8E+3	2E+4
Lu-176	2E-09	3E-09	1E+2	7E+2	50
Lu-177m	3E-08	4E-08	1E+3	7E+2	80
Lu-177	9E-07	5E-07	1E+4	2E+3	2E+3
Lu-178m[38]	7E-05	4E-06	1E+5	5E+4	2E+5
Lu-178	5E-05	8E-06	3E+5	4E+4	1E+5
Lu-179	6E-06	3E-06	1E+5	6E+3	2E+4
Hf-170	2E-06	1E-06	4E+4	3E+3	5E+3
Hf-172	4E-09	6E-09	2E+2	1E+3	90
Hf-173	5E-06	2E-06	8E+4	5E+3	1E+4
Hf-175	4E-07	5E-07	2E+4	3E+3	9E+2
Hf-177m[38]	2E-05	1E-06	6E+4	2E+4	6E+4
Hf-178m	5E-10	8E-10	30	3E+2	10
Hf-179m	1E-07	1E-07	6E+3	1E+3	3E+2
Hf-180m	9E-06	1E-06	6E+4	7E+3	2E+4
Hf-181	7E-08	1E-07	4E+3	1E+3	2E+2
Hf-182m[38]	4E-05	4E-06	1E+5	4E+4	9E+4
Hf-182	3E-10	5E-10	20	2E+2	0.8
Hf-183[38]	2E-05	4E-06	1E+5	2E+4	5E+4
Hf-184	3E-06	1E-06	4E+4	2E+3	6E+3
Ta-172[38]	4E-05	5E-06	1E+5	4E+4	1E+5
Ta-173	7E-06	3E-06	1E+5	7E+3	2E+4
Ta-174[38]	4E-05	5E-06	2E+5	3E+4	9E+4
Ta-175	6E-06	1E-06	6E+4	6E+3	1E+4
Ta-176	5E-06	1E-06	3E+4	4E+3	1E+4
Ta-177	7E-06	4E-06	1E+5	1E+4	2E+4
Ta-178	3E-05	3E-06	1E+5	2E+4	7E+4
Ta-179	4E-07	1E-06	7E+4	2E+4	9E+2
Ta-180m	2E-05	9E-06	3E+5	2E+4	6E+4
Ta-180	1E-08	4E-08	1E+3	1E+3	20

	10CFR20 DAC uCi/mL	10CFR835 DAC uCi/mL	10CFR835 DAC Bq/M^3	10CFR20 ALIs uCi Ingestion	10CFR20 ALIs uCi Inhalation
Ta-182m[38]	2E-04	6E-06	2E+5	2E+5	4E+5
Ta-182	6E-08	7E-08	2E+3	8E+2	1E+2
Ta-183	4E-07	2E-07	1E+4	9E+2	1E+3
Ta-184	2E-06	8E-07	3E+4	2E+3	5E+3
Ta-185[38]	3E-05	5E-06	1E+5	3E+4	6E+4
Ta-186[38]	9E-05	7E-06	2E+5	5E+4	2E+5
W-176	2E-05	3E-06	1E+5	1E+4	5E+4
W-177	4E-05	5E-06	2E+5	2E+4	9E+4
W-178	8E-06	3E-06	1E+5	5E+3	2E+4
W-179[38]	7E-04	1E-04	5E+6	5E+5	2E+6
W-181	1E-05	1E-05	4E+5	2E+4	3E+4
W-185	3E-06	2E-06	9E+4	2E+3	7E+3
W-187	4E-06	1E-06	5E+4	2E+3	9E+3
W-188	5E-07	6E-07	2E+4	4E+2	2E+3
Re-177[38]	1E-04	1E-05	4E+5	9E+4	3E+5
Re-178[38]	1E-04	1E-05	3E+5	7E+4	3E+5
Re-181	4E-06	1E-06	4E+4	5E+3	8E+3
Re-182[26]	9E-07	3E-07	1E+4	1E+3	1E+4
Re-182[27]	5E-06	1E-06	4E+4	1E+3	2E+3
Re-184m	2E-07	1E-07	4E+3	2E+3	4E+2
Re-184	6E-07	3E-07	1E+4	2E+3	2E+3
Re-186m	6E-08	7E-08	2E+3	1E+3	2E+2
Re-186	7E-07	4E-07	1E+4	2E+3	2E+3
Re-187	4E-05	1E-04	4E+6	6E+5	1E+5
Re-188m	6E-05	2E-05	1E+6	8E+4	1E+5
Re-188	2E-06	7E-07	2E+4	2E+3	3E+3
Re-189	2E-06	9E-07	3E+4	3E+3	4E+3
Os-180[38]	2E-04	1E-05	3E+5	1E+5	4E+5
Os-181[38]	2E-05	3E-06	1E+5	1E+4	4E+4
Os-182	2E-06	9E-07	3E+4	2E+3	4E+3

	10CFR20 DAC uCi/mL	10CFR835 DAC uCi/mL	Bq/M^3	10CFR20 ALIs uCi Ingestion	Inhalation
Os-185	2E-07	4E-07	1E+4	2E+3	5E+2
Os-189m	7E-05	7E-05	2E+6	8E+4	2E+5
Os-191m	7E-06	4E-06	1E+5	1E+4	2E+4
Os-191	6E-07	3E-07	1E+4	2E+3	1E+3
Os-193	1E-06	8E-07	3E+4	2E+3	3E+3
Os-194	3E-09	1E-08	4E+2	4E+2	8
Ir-182[38]	5E-05	7E-06	2E+5	4E+4	1E+5
Ir-184	1E-05	1E-06	6E+4	8E+3	2E+4
Ir-185	4E-06	1E-06	7E+4	5E+3	1E+4
Ir-186[28]	X	7E-07	2E+4	X	X
Ir-186[29]	X	4E-06	1E+5	X	X
Ir-186	2E-06	X	X	2E+3	6E+3
Ir-187	1E-05	3E-06	1E+5	1E+4	3E+4
Ir-188	1E-06	6E-07	2E+4	2E+3	3E+3
Ir-189	1E-06	1E-06	4E+4	5E+3	4E+3
Ir-190m[38]	8E-05	X	X	2E+5	2E+5
Ir-190m[30]	X	2E-06	7E+4	X	X
Ir-190m[31]	X	5E-05	1E+6	X	X
Ir-190	4E-07	2E-07	8E+3	1E+3	9E+2
Ir-192m	6E-09	1E-07	1E+3	3E+3	90
Ir-192	9E-08	1E-07	4E+3	3E+2	2E+2
Ir-194m	3E-08	8E-08	2E+3	6E+2	90
Ir-194	8E-07	7E-07	2E+4	1E+3	2E+3
Ir-195m	9E-06	2E-06	7E+4	8E+2	2E+4
Ir-195	2E-05	4E-06	1E+5	1E+4	4E+4
Pt-186	2E-05	3E-06	1E+5	1E+4	4E+4
Pt-188	7E-07	8E-07	3E+4	2E+3	2E+3
Pt-189	1E-05	3E-06	1E+5	1E+4	3E+4
Pt-191	4E-06	1E-06	7E+4	4E+3	8E+3
Pt-193m	3E-06	2E-06	8E+4	3E+3	6E+3

	10CFR20 DAC	10CFR835 DAC		10CFR20 ALIs uCi	
	uCi/mL	uCi/mL	Bq/M^3	Ingestion	Inhalation
Pt-193	1E-05	2E-05	7E+5	4E+4	2E+4
Pt-195m	2E-06	1E-06	5E+4	2E+3	4E+3
Pt-197m[38]	2E-05	7E-06	2E+5	2E+4	4E+4
Pt-197	4E-06	3E-06	1E+5	3E+3	1E+4
Pt-199[38]	6E-05	1E-05	4E+5	5E+4	1E+5
Pt-200	1E-06	1E-06	5E+4	1E+3	3E+3
Au-193	8E-06	3E-06	1E+5	9E+3	2E+4
Au-194	2E-06	9E-07	3E+4	3E+3	5E+3
Au-195	2E-07	4E-07	1E+4	5E+3	4E+2
Au-198m	5E-07	2E-07	1E+4	1E+3	1E+3
Au-198	7E-07	5E-07	1E+4	1E+3	2E+3
Au-199	2E-06	7E-07	2E+4	3E+3	4E+3
Au-200m	1E-06	4E-07	1E+4	1E+3	3E+3
Au-200	3E-05	7E-06	2E+5	3E+4	6E+4
Au-201	9E-05	9E-06	3E+5	7E+4	2E+5
Hg-193m[32]	5E-06	1E-06	4E+4	4E+3	1E+4
Hg-193m	3E-06	1E-06	4E+4	3E+3	8E+3
Hg-193m[10]	4E-06	1E-07	6E+3	X	8E+3
Hg-193[32]	3E-05	5E-06	1E+5	2E+4	6E+4
Hg-193	2E-05	4E-06	1E+5	2E+4	4E+4
Hg-193[10]	1E-05	5E-07	1E+4	X	3E+4
Hg-194[32]	1E-08	2E-08	1E+3	20	30
Hg-194	2E-05	3E-08	1E+3	8E+2	40
Hg-194[10]	1E-08	1E-08	5E+2	X	30
Hg-195m[32]	3E-06	1E-06	5E+4	3E+3	6E+3
Hg-195m	2E-06	8E-07	3E+4	2E+3	4E+3
Hg-195m[10]	2E-06	6E-08	2E+3	X	4E+3
Hg-195[32]	2E-05	6E-06	2E+5	2E+4	5E+4
Hg-195	1E-05	6E-06	2E+5	1E+4	3E+4
Hg-195[10]	1E-05	4E-07	1E+4	X	3E+4

	10CFR20 DAC uCi/mL	10CFR835 DAC uCi/mL	10CFR835 DAC Bq/M^3	10CFR20 ALIs uCi Ingestion	10CFR20 ALIs uCi Inhalation
Hg-197m[32]	4E-06	1E-06	5E+4	4E+3	9E+3
Hg-197m	2E-06	8E-07	3E+4	3E+3	5E+3
Hg-197m[10]	2E-06	9E-08	3E+3	X	5E+3
Hg-197[32]	6E-06	4E-06	1E+5	7E+3	1E+4
Hg-197	4E-06	2E-06	7E+4	6E+3	9E+3
Hg-197[10]	4E-06	1E-07	4E+3	X	8E+3
Hg-199m[32]	7E-05	8E-06	3E+5	6E+4	2E+5
Hg-199m[38]	6E-05	5E-06	1E+5	6E+4	1E+5
Hg-199m[10]	3E-05	3E-06	1E+5	X	8E+4
Hg-203[32]	3E-07	7E-07	2E+4	5E+2	8E+2
Hg-203	5E-07	2E-07	1E+4	2E+3	1E+3
Hg-203[10]	4E-07	8E-08	2E+3	X	8E+2
Tl-194m[38]	6E-05	5E-06	2E+5	5E+4	2E+5
Tl-194[38]	2E-04	2E-05	8E+5	3E+5	6E+5
Tl-195[38]	5E-05	6E-06	2E+5	6E+4	1E+5
Tl-197	5E-05	8E-06	2E+5	7E+4	1E+5
Tl-198m[38]	2E-05	2E-06	9E+4	3E+4	5E+4
Tl-198	1E-05	1E-06	5E+4	2E+4	3E+4
Tl-199	4E-05	5E-06	2E+5	6E+4	8E+4
Tl-200	5E-06	8E-07	3E+4	8E+3	1E+4
Tl-201	9E-06	4E-06	1E+5	2E+4	2E+4
Tl-202	2E-06	1E-06	5E+4	4E+3	5E+3
Tl-204	9E-07	9E-07	3E+4	2E+3	2E+3
Pb-195m[38]	8E-05	7E-06	2E+5	6E+4	2E+5
Pb-198	3E-05	2E-06	9E+4	3E+4	6E+4
Pb-199[38]	3E-05	4E-06	1E+5	2E+4	7E+4
Pb-200	3E-06	1E-06	4E+4	3E+3	6E+3
Pb-201	8E-06	2E-06	7E+4	7E+3	2E+4
Pb-202m	1E-05	1E-06	6E+4	9E+3	3E+4
Pb-202	2E-08	4E-08	1E+3	1E+2	50

	10CFR20 DAC	10CFR835 DAC		10CFR20 ALIs uCi	
	uCi/mL	uCi/mL	Bq/M³	Ingestion	Inhalation
Pb-203	4E-06	2E-06	7E+4	5E+3	9E+3
Pb-205	6E-07	9E-07	3E+4	4E+3	1E+3
Pb-209	2E-05	9E-06	3E+5	2E+4	6E+4
Pb-210	1E-10	1E-10	5	0.6	0.2
Pb-211[38]	3E-07	4E-08	1E+3	1E+4	6E+2
Pb-212	2E-08	5E-09	2E+2	80	30
Pb-214[38]	3E-07	4E-08	1E+3	9E+3	8E+2
Bi-200[38]	4E-05	4E-06	1E+5	3E+4	8E+4
Bi-201[38]	1E-05	2E-06	1E+5	1E+4	3E+4
Bi-202[38]	2E-05	2E-06	9E+4	1E+4	4E+4
Bi-203	3E-06	7E-07	2E+4	2E+3	6E+3
Bi-205	5E-07	4E-07	1E+4	1E+3	1E+3
Bi-206	4E-07	2E-07	8E+3	6E+2	9E+2
Bi-207	1E-07	1E-07	6E+3	1E+3	4E+2
Bi-210m	3E-10	2E-10	9	40	0.7
Bi-210	1E-08	9E-09	3E+2	8E+2	30
Bi-212[38]	1E-07	8E-09	3E+2	5E+3	2E+2
Bi-213[38]	1E-07	7E-09	2E+2	7E+3	3E+2
Bi-214[38]	3E-07	1E-08	4E+2	2E+4	8E+2
Po-203[38]	3E-05	4E-06	1E+5	3E+4	6E+4
Po-205[38]	2E-05	3E-06	1E+5	2E+4	4E+4
Po-207	1E-05	1E-06	6E+4	8E+3	3E+4
Po-210	3E-10	2E-10	9	3	0.6
At-207[38]	2E-08	2E-07	1E+4	6E+3	2E+3
At-211	2E-08	5E-09	1E+2	1E+2	50
Rn-220[33]	X	1E-08	6E+2	X	X
Rn-220[34]	7E-06	X	X	X	2E+4
Rn-220[35]	9E-09	X	X	X	20
Rn-222[33]	X	8E-08	3E+3	X	X
Rn-222[34]	4E-06	X	X	X	1E+4

	10CFR20 DAC	10CFR835 DAC		10CFR20 ALIs uCi	
	uCi/mL	uCi/mL	Bq/M^3	Ingestion	Inhalation
Rn-222[35]	3E-08	X	X	X	1E+2
Fr-222[38]	2E-07	1E-08	3E+2	2E+3	5E+2
Fr-223[38]	3E-07	4E-07	1E+4	6E+2	8E+2
Ra-223	3E-10	9E-11	3	50	0.7
Ra-224	7E-10	2E-10	8	8	2
Ra-225	3E-10	1E-10	4	8	0.7
Ra-226	3E-10	2E-10	9	2	0.6
Ra-227[38]	6E-06	8E-07	3E+4	2E+4	1E+4
Ra-228	5E-10	1E-10	5	2	1
Ac-224	1E-08	5E-09	2E+2	2E+3	30
Ac-225	1E-10	8E-11	3	50	0.3
Ac-226	1E-09	5E-10	20	1E+2	3
Ac-227	2E-13	2E-13	1E-2	0.2	4E-4
Ac-228	4E-09	6E-09	2E+2	2E+3	9
Th-226[38]	6E-08	4E-09	1E+2	5E+3	1E+2
Th-227	1E-10	7E-11	2	1E+2	0.3
Th-228	4E-12	2E-11	0.7	6	1E-2
Th-229	4E-13	2E-12	7E-2	0.6	9E-4
Th-230	3E-12	3E-12	0.1	4	6E-3
Th-231	3E-06	1E-06	5E+4	4E+3	6E+3
Th-232	5E-13	3E-12	0.1	0.7	1E-3
Th-234	6E-08	9E-08	3E+3	3E+2	2E+2
Pa-227[38]	4E-08	4E-09	1E+2	4E+3	1E+2
Pa-228	5E-09	1E-08	3E+2	1E+3	10
Pa-230	1E-09	9E-10	30	6E+2	40
Pa-231	6E-13	1E-12	4E-2	0.2	2E-3
Pa-232	9E-09	1E-08	6E+2	1E+3	20
Pa-233	2E-07	1E-07	6E+3	1E+3	6E+2
Pa-234	3E-06	7E-07	2E+4	2E+3	7E+3
U-230	1E-10	4E-11	1	4	0.3

	10CFR20 DAC uCi/mL	10CFR835 DAC uCi/mL	Bq/M^3	10CFR20 ALIs uCi Ingestion	Inhalation
U-231	2E-06	1E-06	4E+4	4E+3	5E+3
U-232	3E-12	2E-11	0.7	2	8E-3
U-233	2E-11	7E-11	2	10	4E-2
U-234	2E-11	7E-11	2	10	4E-2
U-235	2E-11	8E-11	3	10	4E-2
U-236	2E-11	7E-11	2	10	4E-2
U-237	6E-07	3E-07	1E+4	2E+3	2E+3
U-238	2E-11	8E-11	3	10	4E-2
U-239[38]	7E-05	9E-06	3E+5	7E+4	2E+5
U-240	1E-06	6E-07	2E+4	1E+3	2E+3
U-Natural	2E-11	X	X	10	5E-2
Np-232[38]	7E-07	3E-06	1E+5	1E+5	5E+2
Np-233[38]	1E-03	7E-05	2E+6	8E+5	3E+6
Np-234	1E-06	5E-07	2E+4	2E+3	3E+3
Np-235	3E-07	1E-06	4E+4	2E+4	8E+2
Np-236[36]	9E-12	4E-11	1	3	5E-2
Np-236m[37]	1E-08	5E-08	1E+3	3E+3	30
Np-237	2E-12	8E-12	0.3	0.5	4E-3
Np-238	3E-08	1E-07	4E+3	1E+3	60
Np-239	9E-07	5E-07	1E+4	2E+3	2E+3
Np-240[38]	3E-05	2E-06	8E+4	2E+4	6E+4
Pu-234	8E-08	3E-08	1E+3	8E+3	2E+2
Pu-235[38]	1E-03	8E-05	3E+6	9E+5	3E+6
Pu-236	8E-12	1E-11	0.6	20	2E-2
Pu-237	1E-06	1E-06	6E+4	1E+4	3E+3
Pu-238	3E-12	6E-12	0.2	0.9	7E-3
Pu-239	3E-12	5E-12	0.2	0.83	6E-3
Pu-240	3E-12	5E-12	0.2	0.8	6E-3
Pu-241	1E-10	2E-10	10	40	0.3
Pu-242	3E-12	5E-12	0.2	0.8	7E-3

	10CFR20 DAC	10CFR835 DAC		10CFR20 ALIs uCi	
	uCi/mL	uCi/mL	Bq/M^3	Ingestion	Inhalation
Pu-243	2E-05	5E-06	1E+5	2E+4	4E+4
Pu-244	3E-12	5E-12	0.2	0.8	7E-3
Pu-245	2E-06	8E-07	3E+4	2E+3	4E+3
Pu-246	1E-07	8E-08	3E+3	4E+2	3E+2
Am-237[38]	1E-04	8E-06	3E+5	8E+4	3E+5
Am-238[38]	1E-06	2E-06	9E+4	4E+4	3E+3
Am-239	5E-06	1E-06	6E+4	5E+3	1E+4
Am-240	1E-06	7E-07	2E+4	2E+3	3E+3
Am-241	3E-12	5E-12	0.1	0.8	6E-3
Am-242m	3E-12	5E-12	0.1	0.8	6E-3
Am-242	4E-08	4E-08	1E+3	4E+3	80
Am-243	3E-12	5E-12	0.1	0.8	6E-3
Am-244m[38]	2E-06	3E-06	1E+5	6E+4	4E+3
Am-244	8E-08	1E-07	5E+3	3E+3	2E+2
Am-245	3E-05	5E-06	2E+5	3E+4	8E+4
Am-246m[38]	8E-05	6E-06	2E+5	5E+4	2E+5
Am-246[38]	4E-05	2E-06	9E+4	3E+4	1E+5
Cm-238	5E-07	1E-07	4E+3	2E+4	1E+3
Cm-240	2E-10	2E-10	7	60	0.6
Cm-241	1E-08	2E-08	8E+2	1E+3	30
Cm-242	1E-10	1E-10	5	30	0.3
Cm-243	4E-12	7E-12	0.2	10	9E-3
Cm-244	5E-12	9E-12	0.3	10	1E-2
Cm-245	3E-12	5E-12	0.1	0.7	6E-3
Cm-246	3E-12	5E-12	0.1	0.7	6E-3
Cm-247	3E-12	5E-12	0.2	0.8	6E-3
Cm-248	7E-13	1E-12	5E-2	0.2	2E-3
Cm-249[38]	7E-06	8E-06	3E+5	5E+4	2E+4
Cm-250	1E-13	2E-13	8E-3	4E-2	3E-4
Bk-245	5E-07	3E-07	1E+4	2E+3	1E+3

	10CFR20 DAC uCi/mL	10CFR835 DAC uCi/mL	Bq/M^3	10CFR20 ALIs uCi Ingestion	Inhalation
Bk-246	1E-06	8E-07	3E+4	3E+3	3E+3
Bk-247	2E-12	3E-12	0.1	0.5	4E-3
Bk-249	7E-10	1E-09	50	2E+2	20
Bk-250	1E-07	2E-07	9E+3	9E+3	3E+2
Cf-244[38]	2E-07	1E-08	5E+2	3E+4	6E+2
Cf-246	4E-09	1E-09	50	4E+2	90
Cf-248	3E-11	5E-11	2	80	6E-2
Cf-249	2E-12	3E-12	0.1	0.5	4E-3
Cf-250	4E-12	7E-12	0.2	10	9E-3
Cf-251	2E-12	3E-12	0.1	0.5	4E-3
Cf-252	8E-12	1E-11	0.6	20	2E-2
Cf-253	7E-10	5E-10	20	2E+2	20
Cf-254	7E-12	2E-11	0.8	20	2E-2
Es-250	2E-07	4E-07	1E+4	4E+4	5E+2
Es-251	4E-07	3E-07	1E+4	7E+3	9E+2
Es-253	6E-10	2E-10	9	2E+2	10
Es-254m	4E-09	1E-09	50	3E+2	10
Es-254	3E-11	6E-11	2	80	7E-2
Fm-252	5E-09	2E-09	80	5E+2	10
Fm-253	4E-09	1E-09	60	1E+3	10
Fm-254	4E-08	6E-09	2E+2	3E+3	90
Fm-255	9E-09	2E-09	80	5E+2	20
Fm-257	7E-11	1E-10	4	20	0.2
Md-257	4E-08	2E-08	1E+3	7E+3	80
Md-258	1E-10	1E-10	4	30	0.2

External Exposure in a Cloud of Airborne Material

	10CFR835		10CFR20
	uCi/mL	Bq/M^3	uCi/mL
Ar-37	10	4E+10	10
Ar-39	4E-04	1E+07	4E-04
Ar-41	1E-06	3E+04	3E-06
Kr-74	1E-06	4E+04	3E-06
Kr-76	3E-06	1E+05	9E-06
Kr-77	1E-06	5E+04	4E-06
Kr-79	5E-06	2E+05	2E-05
Kr-81	2E-04	9E+06	7E-04
Kr-83m	2E-02	9E+08	1E-02
Kr-85	2E-04	9E+06	1E-04
Kr-85m	9E-06	3E+05	2E-05
Kr-87	1E-06	5E+04	5E-06
Kr-88	6E-07	2E+04	2E-06
Xe-120	3E-06	1E+05	1E-05
Xe-121	7E-07	2E+04	2E-06
Xe-122	2E-05	1E+06	7E-05
Xe-123	2E-06	8E+04	6E-06
Xe-125	5E-06	2E+05	2E-05
Xe-127	5E-06	2E+05	1E-05
Xe-129m	6E-05	2E+06	2E-04
Xe-131m	1E-04	6E+06	4E-04
Xe-133	4E-05	1E+06	1E-04
Xe-133m	4E-05	1E+06	1E-04
Xe-135	5E-06	2E+05	1E-05
Xe-135m	3E-06	1E+05	9E-06
Xe-138	1E-06	4E+04	4E-06

STCs = Special Tritium Compounds

1 = Water (HTO) form	21 = Methyl
2 = Elemental (HT form)	22 = 12 h half-life
3 = water and elemental	23 = 34 yr half-life
4 = Insoluble	24 = 24 h half-life
5 = Soluble	25 = 5 h half-life
6 = Vapor form	26 = 64 h half-life
7 = As CO	27 = 12 h half-life
8 = As CO_2	28 = 16 h half-life
9 = compounds	29 = 2 h half-life
10 = Vapor	30 = 3 h half-life
11 = Inorganic	31 = 1 h half-life
12 = Carbonyl	32 = Organic
13 = 66 min half-life	33 = radon-220 with short-lived progeny
14 = 122 min half-life	
15 = 69 min half-life	34 = with progeny removed
16 = 5 h half-life	35 = with progeny present
17 = 16 min half-life	36 = 1E+05 yr half-life
18 = 6 d half-life	37 = 22 h half-life
19 = 9 h half-life	38 = half-life less than 2 hours
20 = 10 min half-life	

For any radionuclide not listed in these tables with decay mode other than alpha emission or spontaneous fission and with radioactive half-life less than two hours, the DAC value shall be 6E-06 uCi/mL (2E+04 Bq/M^3).

The DAC values listed for both 10CFR20 and 10CFR835 were truncated after being calculated from the appropriate ALI values. For 10CFR835 the ALI values were taken from ICRP 68.

Airborne Activity General Dispersion Model

Assume a 1 uCi (37 kBq) release of respirable Pu^{239} inside a large room measuring 12 x 12 x 3 meters with a ventilation turnover rate of 7 volumes per hour.

The General Dispersion Model uses this 2π formula for volume. $V = 2/3\pi \times R^3$

Volume in cm^3	30 cm	1 M	10 M
@ distance R	5.65E4	2.09E6	2.09E9
Concentration @ distance R in uCi / cc	1.77E-5	4.78E-7	4.78E-10
Time required for the airborne wave front to reach distance R	13 sec	43 sec	7.15 min

1 CFM sample for 1 week equals 10,080 CF (285.4 M^3)

2 CFM sample for 1 week equals 20,160 CF (571 M^3)

Calculating Airborne Radioactivity (long-lived)

C_S = $R_N / (V \times \xi \times SA \times CE \times CF)$

C_S = activity concentration at end of sample run time

R_N = net counting rate

V = sample volume

ξ = detector efficiency

SA = self-absorption factor

CE = collection efficiency

CF = conversion from disintegrations per unit time to activity

Calculating Airborne Radioactivity (short-lived)

C_S = $R_N / [V \times \xi \times SA \times CE \times CF \times (1-e^{-\lambda Ts}) \times (e^{-\lambda Td})]$

Ts = sample count time

Tb = time elapsed between end of sample collection time and start of sample count time

Ventilation Rates

Ventilation rates of work areas for health physics and industrial hygiene requirements is typically 6 to 7 volume turnovers per hour.

Calculate the ventilation rate in CFM to ventilate a room at 7 volume turnovers per hour given room dimensions of 30 feet by 30 feet by 10 feet. Volume of the room is 30 x 30 x 10 = 9,000 cubic feet. Seven volume turnovers per hour would be 7 times 9,000 cubic feet or 63,000 cubic feet per hour (1,050 CFM) room ventilation rate.

Lung Deposition from ICRP 30

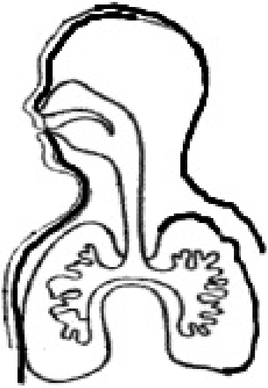
AMAD μ	NP Naso-pharanx	TB Trachea-bronchus	Alveolar
0.1	0.01	0.08	0.61
1	0.3	0.08	0.25
10	0.9	0.08	0.04

Regions of Deposition

Naso-Pharyngeal

Tracheobronchial

Alveolar



AIR MONITORING

Concentration

Concentration is activity per volume of air and may be stated as dpm / cubic meter, µCi / ml, or Bq / cubic meter. DAC (**D**erived **A**ir **C**oncentration) is another way to express airborne radioactivity concentrations as relative hazards.

DPM	=	Sample CPM / Eff (CPM / DPM)
1 µCi	=	2.22 E6 DPM
1 DPM / M^3	=	4.5 E-13 µCi / ml
1 µCi / ml	=	2.22 E12 DPM / M^3
1 Bq	=	1 DPS
DPM / M^3	=	CPM/(Eff x total sample volume in M^3)
µCi / ml	=	CPM/(Eff x 2.22 E6 DPM / µCi x total sample volume in ml)
Bq / M^3	=	CPM / (Eff x 60 DPM / Bq x total sample volume in M^3)
DAC	=	µCi / ml (µCi / ml per DAC {DAC Factor})
1 DAC-h	=	1 DAC exposure for 1 hour
1 DAC-h	=	2.5 mrem = 25 µSv

1 DAC for Pu239 is 4.44 DPM / M^3

Calculate the number of DAC-h on a filter by this formula

$$\# \text{ DAC-h} = \frac{\# \text{ of DPM on filter}}{(\text{Sample flow rate in LPM} \times 1.332E11 \times \text{DAC factor})}$$

Calculate the DPM on a filter to reach 8 DAC-h

DPM = 8 DAC-h x flow rate in LPM x 1.33E11 x DAC factor

Calculate the DAC level on a filter from the # of DPM

$$\text{DAC} = \frac{\# \text{ of DPM}}{(\text{DAC factor} \times \text{LPM} \times \text{time in minutes} \times 2.22E9)}$$

AIR FLOW METER CORRECTIONS

Mass Flow Meters

$Q_S \quad = \quad Q_A\,(P_A/P_S \times T_S/T_A)$

$Q_A \quad = \quad Q_S\,(P_S/P_A \times T_A/T_S)$

where; Q_S is the STP flow rate
Q_A is the ambient flow rate
P_S is STP pressure
P_A is the ambient pressure
T_S is STP temperature
T_A is the ambient temperature

Rotameter Corrections

$Q_A \quad = \quad Q_I \sqrt{(P_S/P_A \times T_A/T_S)}$

$Q_S \quad = \quad Q_I \sqrt{(P_A/P_S \times T_S/T_A)}$

where; Q_I is the rotameter flow indication

This correction assumes the rotameter markings are correct at STP. If the rotameter was calibrated for other than STP then other corrections must be applied.

Note: If the pressure inside the rotameter is less than standard the rotameter will indicate higher than the true standard flow rate but less than the ambient (actual or volumetric) flow rate.

If the rotameter is downstream from the sampling head then the ambient pressure inside the rotameter will be less than the local atmospheric pressure. The ambient pressure inside the rotameter should be used in the calculations.

For personnel protection against particulate airborne radioactivity ambient sample volumes instead of volumes corrected to STP should be used for calculations. The ambient respiratory rate will remain the same as atmospheric pressure changes from STP up to an elevation of approximately 12,000 feet (3,660 Meters).

AIR POLLUTION SAFE LIMITS (mg / m^3)

Pollutant	Limit	Pollutant	Limit
Benzene **	0.3	Iron oxide (fume)	5
Bromine	0.66	Isopropyl alcohol	980
Cadmium *	0.002	Lead (dust & fume)	0.2
CO_2	9,000	Manganese	0.2
Carbon disulfide	31	Mercury	0.01
CO	29	Methanol	0.2
Carbon tetrachloride ***	31	Nitric oxide	30
Chlorine	1.5	NO_2	5.6
Chloroform *	49	Selenium	0.2
Cresol	22	SO_2	5.2
Ethanol	1,880	Sulfuric acid	1
Fluorine	1.6	Tellurium	0.1
Formaldehyde *	0.37	Tetraethyl lead	0.1
Gasoline	890	Toluene	188
Hydrogen cyanide	11	Turpentine	560
Iodine	1	Vinyl chloride **	13
		Zinc oxide (fume)	5
Asbestos **	0.2 fibers / cc		

* Suspected human carcinogen
** Animal carcinogen
*** Confirmed human carcinogen

ELEVATION VS AIR PRESSURE

Elevation		Barometric Pressure		Boiling Point of Water		Speed of Sound	
FT	M	mm Hg	kPa	^{0}C	^{0}F	M/S	MPH
-500	-152	774	103.2	100.5	212.9	340.9	763
0	0	760	101.3	100	212.0	340.3	761
500	152	746	99.5	99.5	211.1	339.7	760
1,000	305	732	97.6	99.0	210.2	339.1	759
1,500	457	720	96.0	98.4	209.2	338.6	757
2,000	610	707	94.3	97.9	208.3	338.0	756
2,500	762	694	92.5	97.4	207.4	337.4	755
3,000	914	681	90.8	97.0	206.6	336.7	753
3,500	1,067	668	89.1	96.4	205.6	336.2	752
4,000	1,219	656	87.5	95.9	204.6	335.6	751
4,500	1,372	644	85.9	95.4	203.7	334.8	749
5,000	1,524	632	84.3	94.9	202.9	334.4	748
5,500	1,676	619	82.5	94.4	202.0	333.8	747
6,000	1,829	609	81.2	93.9	201.1	333.2	745
6,500	1,981	597	79.6	93.3	200.0	332.6	744
7,000	2,134	586	78.1	92.8	199.1	332.2	743
7,500	2,286	575	76.7	92.4	198.3	331.4	741
8,000	2,438	564	75.2	91.8	197.4	330.8	740
9,000	2,743	543	72.4	90.9	195.6	330.1	738
10,000	3,048	523	69.7	89.8	193.7	328.5	735
11,000	3,353	504	67.1	88.8	191.4	327.3	732
12,000	3,658	484	64.5	87.8	190.1	326.0	729
13,000	3,962	464	62.0	86.8	188.2	324.6	726
14,000	4,267	444	59.5	85.8	186.4	323.2	723
15,000	4,572	424	57.0	84.8	184.6	321.8	720
16,000	4,877	404	54.6	83.7	182.7	320.4	717

ELEVATIONS OF MAJOR AIRPORTS AND FACILITIES

		Feet			Feet
AK	Anchorage	144	IL	Bloomington	875
AK	Fairbanks	434	IL	Moline	589
AL	Birmingham	644	IN	Bloomington	845
AL	Dothan	401	IN	Evansville	416
AL	Huntsville	630	KS	Wichita	1,332
AR	Little Rock	260	KY	Lexington	980
AR	Fort Smith	469	KY	Paducah	410
AZ	Flagstaff	7,011	LA	New Orleans	6
AZ	Phoenix	1,133	LA	Shreveport	248
AZ	Tucson	2,641	MA	Boston	20
CA	Imperial	-24	MA	Worcester	1,009
CA	Lake Tahoe	6,264	MD	Hagerstown	704
CA	Sacramento	24	MD	Salisbury	52
CA	Los Angeles	126	ME	Portland	74
CO	Denver	5,431	ME	Presque Island	534
CO	Leadville	9,927	MI	Detroit	626
CO	Pueblo	4,726	MI	Hancock	1,095
CT	Bridgeport	10	MN	Duluth	1,428
CT	New Haven	14	MN	Minneapolis	841
DC	Washington	313	MO	Saint Louis	605
FL	Gainesville	152	MO	Springfield	1,267
FL	Miami	11	MS	Biloxi	28
GA	Atlanta	1,026	MS	Tupelo	346
GA	Savannah	51	MT	Yellowstone	6,644
HI	Honolulu	13	MT	Wolf Point	1,986
HI	Lanai City	1,308	NC	Asheville	2,165
IA	Burlington	698	NC	New Bern	19
IA	Mason City	1,213	ND	Grand Forks	844
ID	Idaho Falls	4,741	ND	Williston	1,962
ID	Lewiston	1,438	NE	Lincoln	1,214

NE	Omaha	983
NH	Lebanon	598
NH	Manchester	234
NJ	Atlantic City	76
NJ	Trenton	213
NM	Albuquerque	5,352
NM	Carlsbad	3,293
NM	Los Alamos	7,200
NM	White Sands	4,197
NV	Ely	6,255
NV	Las Vegas	2,175
NY	Jamestown	1,724
NY	New York	13
OH	Akron	1,228
OH	Cincinnati	897
OH	Cleveland	584
OK	Oklahoma City	1,295
OK	Tulsa	677
OR	Portland	27
OR	Redmond	3,077
PA	Johnstown	2,284
PA	Philadelphia	21
RI	Providence	55
SC	Columbia	236
SC	Myrtle Beach	28
SD	Huron	1,288
SD	Rapid City	3,202
TN	Bristol	1,519
TN	Memphis	332
TX	Dallas	487
TX	El Paso	3,956
UT	Cedar City	5,623
UT	Saint George	2,936
UT	Salt Lake City	4,227
VA	Norfolk	27
VA	Roanoake	1,176
VT	Burlington	334
WA	Bellingham	166
WA	Pullman	2,551
WA	Richland	195
WI	La Crosse	654
WI	Oshkosh	808
WI	Rhinelander	1,623
WV	Bluefield	2,857
WV	Huntington	828
WY	Laramie	7,276
WY	Sheridan	4,021

Lowest Spot in the US
Death Valley, CA -282

Highest Spot in the US
Mt. McKinley, AK 20,320

Lowest Spot in the World
Dead Sea, Israel/Jordan
-1,371

Highest Spot in the World
Mt. Everest, Nepal/China
29,035

INTERNATIONAL AIRPORT ELEVATIONS (FEET)

Addis-Ababa, Ethiopia	7,625
Algiers, Algeria	826
Amsterdam, Netherlands	-13
Athens, Greece	90
Bagdad, Iraq	113
Beijing, China	15
Berlin, Germany	164
Bogota, Columbia	8,355
Bombay, India	27
Buenos Aires, Argentina	66
Cairo, Egypt	366
Calgary, Canada	3,557
Cape Town, South Africa	151
Casablanca, Morocco	656
Damascus, Syria	2,020
Darwin, Australia	94
Dublin, Ireland	222
Geneva, Switzerland	1,411
Helsinki, Finland	167
Istanbul, Turkey	92
Jakarta, Indonesia	86
Jo’burg, South Africa	5,557
Karachi, Pakistan	100
Khartoum, Sudan	1,256
La Paz, Bolivia	13,354
Lima, Peru	105
Lisbon, Portugal	374
London, England	80
Madrid, Spain	1,998
Manila, Phillipines	74
Melbourne, Australia	392
Mexico City, Mexico	7,341
Montreal, Canada	117
Moscow, Russia	623
Nairobi, Kenya	5,327
New Delhi, India	776
Osaka, Japan	39
Panama Cty, Panama	135
Paris, France	292
Perth, Australia	53
Port Moresby, Papua NG	125
Quito, Ecuador	9,228
Recife, Brazil	36
Reykjavik, Iceland	169
Rio de Janeiro, Brazil	16
Rome, Italy	7
Santiago, Chili	1,554
Seoul, South Korea	58
Shanghai, China	15
Shannon, Ireland	47
Singapore, Singapore	65
Stockholm, Sweden	123
Sydney, Australia	6
Taipei, Taiwan	21
Tehran, Iran	3,949
Tel Aviv, Israel	135
Tokyo, Japan	8
Toronto, Canada	569
Tunis, Tunisia	20
Vancouver, Canada	8
Warsaw, Poland	361
Zurich, Switzerland	1,416

COMPOSITION OF AIR

	Symbol	% Volume	Density of Gases g / l
Air	-	100.00	1.2928
Nitrogen	N_2	78.084	1.2506
Oxygen	O_2	20.947	1.4290
Argon	Ar	0.934	1.7840
Carbon Dioxide	CO_2	0.033	1.9770
Neon	Ne	18.2 PPM	0.9002
Helium	He	5.2 PPM	0.1785
Methane	CH_4	2.0 PPM	-
Krypton	Kr	1.1 PPM	3.7
Sulfur Dioxide	SO_2	1.0 PPM	2.927
Hydrogen	H_2	0.5 PPM	0.0899
Nitrous Oxide	N_2O	0.5 PPM	1.977
Xenon	Xe	0.09 PPM	5.9
Ozone	O_3	0.0 to 0.07 PPM	2.144
Ozone - winter	O_3	0.0 to 0.02 PPM	2.144
Nitrogen Dioxide	NO_2	0.02 PPM	1.4494
Iodine	I_2	0.01 PPM	-
Carbon Monoxide	CO	0.0 to trace	1.2500
Ammonia	NH_3	0.0 to trace	0.7710

Fuel Gas	Lower Explosive or Flammable Limit LEL/LFL %	Upper Explosive or Flammable Limit UEL/UFL %
Acetaldehyde	4	60
Acetone	2.6	12.8
Acetylene	2.5	81
Ammonia	15	28
Arsine	5.1	78
Benzene	1.35	6.65
n-Butane	1.86	8.41
iso-Butane	1.80	8.44
iso-Butene	1.8	9.0
Butylene	1.98	9.65
Carbon Disulfide	1.3	50
Carbon Monoxide	12	75
Cyclohexane	1.3	8
Cyclopropane	2.4	10.4
Diethyl Ether	1.9	36
Ethane	3	12.4
Ethylene	2.75	28.6
Ethyl Alcohol	3.3	19
Ethyl Chloride	3.8	15.4
Fuel Oil No.1	0.7	5
Hydrogen	4	75
Isobutane	1.8	9.6
Isopropyl Alcohol	2	12
Gasoline	1.4	7.6
Kerosine	0.7	5
Methane	5	15
Methyl Alcohol	6.7	36
Methyl Chloride	10.7	17.4
Methyl Ethyl Ketone	1.8	10

Fuel Gas	Lower Explosive or Flammable Limit LEL/LFL %	Upper Explosive or Flammable Limit UEL/UFL %
Naphthalene	0.9	5.9
n-Heptane	1.0	6.0
n-Hexane	1.25	7.0
n-Pentene	1.65	7.7
Neopentane	1.38	7.22
Neohexane	1.19	7.58
n-Octane	0.95	3.20
iso-Octane	0.79	5.94
n-Pentane	1.4	7.8
iso-Pentane	1.32	9.16
Propane	2.1	10.1
Propylene	2.0	11.1
Silane	1.5	98
Styrene	1.1	6.1
Toluene	1.27	6.75
Triptane	1.08	6.69
p-Xylene	1.0	6.0

Note! The limits indicated are for gas, air and oxygen at *20^oC* and atmospheric pressure.

29CFR1910.134 Oxygen Deficient Atmospheres for which the employer may rely on atmosphere-supplying respirators

Altitude less than 3,001 feet	16.0 -19.5 % O_2
Altitude 3,001 to 4,000 feet	16.4 -19.5 % O_2
Altitude 4,001 to 5,000 feet	17.1 -19.5 % O_2
Altitude 5,001 to 6,000 feet	17.8 -19.5 % O_2
Altitude 6,001 to 7,000 feet	18.5 -19.5 % O_2
Altitude 7,001 to 8,000 (1) feet	19.3 -19.5 % O_2

(1) Above 8,000 feet the exception does not apply. Oxygen enriched breathing air must be supplied above 14,000 feet.

RADON FACTS

1 working level	=	3 DAC Rn^{222} (including progeny)
	=	1.3 E5 MeV / liter of air α energy
	=	100 pCi / liter (1 E-7 μCi / ml)
	=	20.8 μJoules / m^3
1 working level-month	=	1 rem CEDE
10,000 pCi / l in water	≈	1pCi / l in air thru evaporation.

EPA ACTION LEVELS FOR RADON GAS IN HOMES

Concentration (pCi/l)	Sampling frequency
0 - 4	initial & no follow-up
4 - 20	one year & follow-up
20 - 200	3 month & follow-up
>200	implement radon reduction methods

4 pCi / l in living area ≈ 1.03 working level-month ≈ 1 rem

PROPOSED EPA ACTION LEVELS FOR RADON IN DRINKING WATER

Maximum Contaminant Level - MCL is 300 pCi / L of radon in water of community water systems.
Alternative Maximum Contaminant Level - AMCL is 4,000 pCi / L of radon in water of community water systems.

To comply with the AMCL limit the state or the CWS (Community Water System) must implement a Multi-Media Mitigation plan to address the radon in the air of residences. The proposed rule would not apply to CWSs that use soley surface water.

The proposed rule requires monitoring for radon in drinking water. The monitoring frequency varies from once per quarter to once in 9 years based on radon concentrations.

Thoron (Rn^{220}) Decay Chain from Thorium-232
1st Progeny kev and % abundance

Rn^{220} 56s	Po^{216}	α 6288 (99.9), 5747 (0.1) γ av. 550 (0.1)
Po^{216} 0.15s	Pb^{212}	α 6779 (99.998)
Pb^{212} 10.64h	Bi^{212}	$β^-$ 158 (5.22), 334 (85.1), 573 (9.9) γ 115 (0.6), 239 (44.6), 300 (3.4) Bi x-rays 11 (15.5), 75 (10.7), 77 (18), 87 (8)

Bi^{212} decays 64 % of the time by $β^-$ to Po^{212} and 36 % of the time by α to Tl^{208}

Bi^{212} 60.6m	Tl^{208} Po^{212}	α 5767 (0.6), 6050 (25.2), 6090 (9.6) $β^-$ 625 (3.4), 1519 (8), 2246 (48.4) γ 727 (11.8), 785 (1.97), 1621 (2.75) Tl x-rays 10 (7.7)
Po^{212} 304ns	Pb^{208}	α 8785 (100)
Tl^{208} 3.05m	Pb^{208}	$β^-$ 1283 (23.2), 1517 (22.7), 1794 (49.3) γ 511 (21.6), 583 (84.2), 860 (12.46), 2614 (99.8) Pb x-rays 11 (2.9), 73 (2.0), 75 (3.4), 85 (1.5)

Pb^{208} is stable

Radon (Rn^{220}) Decay Chain from Uranium-238

1st Progeny kev and % abundance

Rn^{222}	Po^{218}	α 5490 (99.92), 4986 (0.08)
3.82d		γ av. 512 (0.08)

Po^{218} decays 99.98 % of the time by α to Pb^{214} & 0.02 % of the time by β^- to At^{218}

Po^{218}	Pb^{214}	α 6003 (99.98)
3.05m	At^{218}	β^- 330 (0.02)

At^{218}	Bi^{214}	α 6650 (6), 6700 (94)
2s		

Pb^{214}	Bi^{214}	β^- 672 (48), 729 (42.5), 1024 (6.3)
26.8m		γ 242 (7.49), 295 (19.2), 352 (37.2)
		Bi x-rays 11 (13.5), 75 (6.2), 77 (10.5), 87 (4.7)

Bi^{214} decays 99.98% of the time by β^- to Po^{214} & 0.02% of the time by α to Tl^{210}

Bi^{214}	Po^{214}	β^- 1505 (17.7), 1540 (17.9), 3270 (17.2)
19.9m		γ 609 (46.3), 1120 (15.1), 1764 (15.8)
		Po x-rays 11 (o.5), 77 (0.36), 79 (0.6), 90 (0.3)
	Tl^{210}	α 5450 (0.012), 5510 (0.008)

Po^{214}	Pb^{210}	α 7687 (99.989), 6892 (0.01)
164 μs		γ 797 (0.013)

Tl^{210} 1.30m	Pb^{210}	β^- 1320 (25), 1870 (56), 2340 (19) γ 298 (79), 800 (99), 1310 (21) Pb x-rays 11 (13), 73 (2.5), 75 (4.3), 85 (1.9)
Pb^{210} 22.3 y	Bi^{210}	β^- 17 (80.2), 63 (19.8) γ 47 (4.05) Bi x-rays 11 (24.3)

Bi^{210} decays ~100 % of the time by β^- to Po^{210} & 0.00013 % of the time by α to Tl^{206}

Bi^{210} 5.01d	Po^{210} Tl^{206}	β^- 1161 (99.9998) α 4650 (0.00007), 4690 (0.00005)
Po^{210} 138.4d	Pb^{206}	α 5305 (99.9989)
Tl^{206} 4.19m	Pb^{206}	β^- 1520 (100)

Pb^{206} is stable

ABBREVIATIONS

ampere	A, or amp
angstrom unit	A, or Å
atmosphere	atm
atomic weight	at. wt.
becquerel	Bq
cubic foot	ft^3, or cu ft
cubic feet per minute	ft^3/min, or cfm
cubic inch	in^3, or cu. in.
cubic meter	m^3, or cu m
curie	Ci
day	day, or d
degree	deg, or ^{0}
disintegrations per minute	dpm
foot	ft
gallon	gal
gallons per minute	gpm
gram	g or gm
hour	h, or hr
inch	in.
liter	liter, or L
meter	m
micron	μ, μm, or mu
minute	min, or m
pounds per square inch	lb/in^2, or psi
roentgen	R
second	sec, or s
square centimeter	cm^2, or sq cm
square foot	ft^2, sq ft
square meter	m^2, or sq m
volt	V, or v
watt	W, or w
year	yr, or y

CONVERSION OF UNITS

Length

1 angstrom (Å)	=	1E-8 cm	1 cm	=	1E8 Å
1 inch	=	2.54 cm	1 cm	=	0.3937 in
1 meter	=	3.2808 feet	1 foot	=	0.3048 m
1 kilometer	=	0.6214 miles	1 mile	=	1.609 km
1 mile	=	5,280 feet	1 foot	=	1.894E-4 mile
1 micron (µm)	=	1E-6 meters	1 m	=	1E6 µm
1 mil	=	1E-3 inches	1 inch	=	1E3 mil
1 thousandth of an inch (0.001")	=	2.54E-2 mm	1 mm	=	0.03937 in
1 yard	=	0.9144 meters	1 m	=	1.0936 yard

Area

1 acre	=	43,560 ft^2	1 ft^2	=	2.296E-5 acre
1 barn	=	1E-24 cm^2	1 cm^2	=	1E24 barn
1 cm^2	=	0.1550 in^2	1 in^2	=	6.452 cm^2
1 m^2	=	10.764 ft^2	1 ft^2	=	0.0929 m^2
1 m^2	=	3.861E-7 $mile^2$	1 $mile^2$	=	2.59E6 m^2
1 $mile^2$	=	640 acres	1 acre	=	1.5625E-3 $mile^2$

Volume

1 cm^3 (cc)	=	3.5315E-5 ft^3	1 ft^3	=	28,316 cm^3
1 cm^3	=	1E-6 m^3	1 m^3	=	1E6 cm^3
1 cm^3	=	0.03381 ounces	1 ounce	=	29.58 cm^3
1 ft^3	=	28.316 liters	1 liter	=	0.035315 ft^3
1 ft^3	=	7.481 gallons	1 gal	=	0.1337 ft^3
1 liter	=	1.057 quarts	1 quart	=	0.946 liter
1 liter	=	0.2642 gallons	1 gal	=	3.785 liter
1 liter	=	61.0237 in^3	1 in^3	=	0.016387 liter
1 m^3	=	35.315 ft^3	1 ft^3	=	0.028316 m^3
1 m^3	=	1,000 liters	1 liter	=	1E-3 m^3
1 milliliter (ml)	=	1 cm^3	1 cm^3	=	1 ml

Mass

1 gram	= 0.03527 ounces	1 ounce	= 28.35 g
1 kilogram	= 2.2046 pounds	1 lbs	= 0.4536 kg
1 pound	= 16 ounces	1 ounce	= 0.0625 lb
1 pound	= 453.59 grams	1 gram	= 2.2046E-3 lb

Density

1 gram / cm^3	= 62.428 lbs / ft^3	1 lb/ft^3	= 0.016018 g/cm^3
1 gram / cm^3	= 8.345 lbs / gal	1 lb/gal	= 0.1198 g/cm^3

Concentration

1 Bq / M^3	= 60 DPM / M^3	1 DPM/M^3	= 0.0167 Bq/M^3
1 Bq / M^3	= 0.027027pCi/L	1 pCi / L	= 37 Bq / M^3
1 pCi / L	= 1E-9 µCi / cc	1 µCi / cc	= 1E9 pCi / L
1 µCi / cc	= 2.22E12 DPM/M^3		
1 DPM / M^3	= 4.5045E-13µCi/cc		
1 µCi / cc	= 3.7E10 Bq / M^3		
1 Bq / M^3	= 2.7027E-11 µCi/cc		
1 pCi / ft^3	= 3.5315E-11 µCi / cc		
1 µCi / cc	= 2.8316E10 pCi / ft^3		

Pressure

1 atmosphere	= 1.01325 bars	1 bar	= 0.9869 atm
1 atmosphere	= 101.325 kPa	1 kPa	= 0.009869 atm
1 atmosphere	= 14.696 lbs / in^2	1 lbs / in^2	= 0.06805 atm
1 atmosphere	= 760 mm Hg	1 mm Hg	= 0.001316 atm
1 atmosphere	= 29.9213 "Hg	1 "Hg	= 0.033421 atm
1 atmosphere	= 33.8995 feet H_2O	1 ft H_2O	= 0.0295 atm
1 bar	= 1E6 dynes / cm^2	1 dyne/cm^2	= 1E-6 bar
1 dyne/cm^2	= 0.1 Pascals	1 Pascal	= 10 dyne/cm^2
1 Torr	= 1 mm Hg	1 mm Hg	= 1 Torr
1 dyne/cm^2	= 1.0197E-3 g/cm^2	1 g/cm^2	= 980.68 dyne/cm^2

Radiological

1 rad	=	100 ergs / g
1 erg / g	=	0.01 rad
1 rad	=	6.242E13 eV / g
1 eV / g	=	1.602E-13 roentgen
1 roentgen	=	87.7 ergs / g of air
1 erg / g of air	=	0.0114 roentgen
1 roentgen	=	1.61E12 ion pairs/g of air
1 ion pair / g of air	=	6.21E-13 roentgen
1 roentgen	=	5.47E13 eV / g of air
1 eV / g of air	=	1.828E-14 roentgen
1 roentgen	=	0.98 rads (in soft tissue)
1 rad (in soft tissue)	=	1.02 roentgen
1 rem	=	100 ergs / g in tissue
1 erg /g in tissue	=	0.01 rem
1 sievert (Sv)	=	100 rem
1 rem	=	0.01 Sv
1 sievert	=	1 J / kg
1 curie (Ci)	=	3.7E10 dps
1 dps	=	2.7027E-11 Ci
1 curie	=	2.22E12 dpm
1 dpm	=	4.5045E-13 Ci
1 µCi / m^2	=	222 dpm / cm^2
1 dpm / cm^2	=	0.0045 µCi / m^2
1 megaCi / sq mile	=	0.386 Ci / m^2
1 Ci / m^2	=	2.59 megaCi/sq mile
1 dpm / m^3	=	4.5E-13 µCi / cm^3
1 µCi / cm^3	=	2.22E12 dpm / m^3
1 becquerel (Bq)	=	2.7027E-11 Ci
1 Ci	=	3.7E10 Bq
1 becquerel	=	1 dps
1 dps	=	1 Bq

Radiological

1 BTU	=	1.28E-8 g ^{235}U fissioned
1 g ^{235}U fissioned	=	7.81E7 BTU
1 BTU	=	3.29E13 fissions
1 fission	=	3.04E-14 BTU
1 g ^{235}U fissioned	=	1 megawatt-days
1 MW-days	=	1 g ^{235}U fissioned
1 g ^{235}U fissioned	=	1.8E-2 kilotons TNT
1 kilotons TNT	=	55.6 g ^{235}U fissioned
1 fission	=	8.9058E-18 kW-hours
1 kW-hrs	=	1.123E17 fissions
1 fission	=	3.204E-4 ergs
1 erg	=	3.121E3 fissions
1 fission	=	6.9E-21 Megatons TNT
1 Megatons TNT	=	1.45E20 fissions
1 gray	=	100 rads
1 rad	=	0.01 gray
1 joule (J)	=	6.24E18 eV
1 eV	=	1.602E-19 joule

Others

1 ampere	=	2.998 E9 electrostatic units/sec
3.336E-10 amp	=	1 electrostatic unit/sec
1 ampere	=	6.242 E18 electronic charges/sec
1.602E-19 amp	=	1 electronic charge/sec
1 coulomb	=	6.242 E18 electronic charges
1 electronic charge	=	1.602E-19 coulomb

Power

1 joule/sec	=	1E7 ergs/sec	1 erg/sec	=	1E-7 joule/sec
1 watt	=	1E7 ergs/sec	1 erg/sec	=	1E-7 watt
1 watt	=	1 joule/sec	1 joule/sec	=	1 watt
1 watt	=	0.001341 hp	1 hp	=	745.7 watts
1 BTU/min	=	0.01757 kW	1 kW	=	56.9 BTU/min
1 BTU/min	=	0.023575 hp	1 hp	=	42.4 BTU/min
1 joule	=	9.478E-4 BTU	1 BTU	=	1.055E3 joules
1 joule	=	1E7 ergs	1 erg	=	1E-7 joule
1 calorie, g	=	0.003971 BTU	1 BTU	=	251.8 calories, g

MULTIPLES AND SUBMULTIPLES

1E18	Exa	E	1E2	hecto	h	1E-6	micro	μ
1E15	Peta	P	1E1	deka	da	1E-9	nano	n
1E12	tera	T	1E0	1	1	1E-12	pico	p
1E9	giga	G	1E-1	deci	d	1E-15	femto	f
1E6	mega	M	1E-2	centi	c	1E-18	atto	a
1E3	kilo	k	1E-3	milli	m			

GREEK ALPHABET

A	α	Alpha		ι	Iota		ρ	Rho
	β	Beta		κ	Kappa		σ	Sigma
	γ	Gamma		λ	Lambda		τ	Tau
	δ	Delta	M	μ	Mu		υ	Upsilon
	ϵ	Epsilon		ν	Nu		φ	Phi
	ζ	Zeta		ξ	Xi		χ	Chi
	η	Eta		ο	Omicron		ψ	Psi
	θ	Theta		π	Pi	Ω	ω	Omega

CONSTANTS

Avogadro's number (N_0)	6.02252E23
electron charge (e)	4.80298E-10 esu
electron rest mass (m_e)	9.1091 E-28 g
acceleration of gravity (g)	32.1725 ft / sec^2
@ sea level & 45^0 latitude	980.621 cm / sec^2
Planck's constant (h)	6.625E-27 erg-sec
velocity of light (c)	2.9979E10 cm / sec
	186,280 miles / sec
ideal gas volume (V_0)	22,414 cm^3 / mole (STP)
neutron mass	1.67482E-24 g
proton mass	1.67252E-24 g
ratio of proton to electron mass	1836.13
natural base of logarithms (e)	2.71828
	3.14159
1C	6.2418E18 esus
1A	1 C/sec
1 barn (b)	1E-24 cm^2
charge (e^{-1})	1.6E-19 C
W for air	33.8 eV / ion pair
Universal gas constant (R)	8.32E7 ergs/^{0}C gram mol

A gram-molecular weight of any gas contains Avogadro's number, N_0 (6.02252 E23) atoms and occupies a volume of 22,414 cm^3 at STP.

Temperature

$^0C = (^0F - 32)(5/9)$ $\quad$ $^0F = {}^0C \times 1.8 + 32$

$^0K = {}^0C + 273.1$ $\quad$ $^0R = {}^0F + 459.58$

SURFACE AREA AND VOLUME CALCULATIONS

Triangle A (area) = ½ x b x h;
where b is the base and h is the height of the triangle

Rectangle A (area) = a x b;
where a and b are the lengths of the sides

Rectangular Box V (volume) = w x l x h;
where w is the width, l is the length, and h is the height

Parallelogram (a 4-sided figure with opposite sides parallel)
A (area) = a x h; or a x b x sin ;
where a and b are the length of the sides, h is the altitude (or vertical height), and is the angle between the sides

Trapezoid (a 4-sided figure with two sides parallel)
A (area) = ½ x h (a + b);
where a and b are the length of the sides and h is the height

Regular polygon of *n* sides
A (area) = 1/4 x n x a^2 x cotangent (180^0 / n);
where a is the length of a side and n is the number of sides

Circle A (area) = x r^2; or 1/4 x x d^2;
where r is the radius and d is the diameter

Cube A (area) = 6 x a^2;
V (volume) = a^3;
where a is the length of a side

Cylinder A (area) = 2 x x r x h;
V (volume) = x r^2 x h;
where r is the radius and h is the length of the height

Sphere A (area) = 4 x x r^2; or x d^2;
V (volume) = 4/3 x x r^3 **or** 1/6 x x d^3
where r is the radius and d is the diameter