Radiation Safety & Comparisons of Radiation Doses

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1.0 Introduction

Many radiometric systems are used in industry for widely differing process measurements, monitoring and control. Radiometric measuring methods are often successful where other techniques fail, due to technical and physical reasons. In addition, radiometric methods offer high degrees of measurement integrity, since they are unaffected by chemical and most of the physical characteristics of the products measured.

Radiometric measuring systems use radioactive substances of different types and activities, selected for each type of application. Laws to ensure proper handling and minimum exposure to persons regulate the use of radioactive materials. Properly trained persons must ensure that adequate safety procedures exist and are followed by users of radiometric measurement systems.

We are all exposed to ionizing radiation from the moment of conception. Our environment and even the human body contain naturally occurring radioactive materials. Cosmic radiation originating in space and at the sun contributes to the total background of radiation in which we live. We use x-ray equipment in medicine and in dentistry; our food and beverages also contain naturally occurring radioactive materials.

The levels of radiation encountered by persons during the proper use of our systems are lower than those allowed by international and local regulations. We would be pleased to provide you the best available information about potential health risks and if the topic is new to you, we would like to help you to develop an attitude of healthy respect for such risks rather than unnecessary fear, or conversely, a lack of concern.

1.1 Radiation Exposure of Human Beings

The sources of natural radiation have existed since the creation of the earth, and as long as there is life on this earth, this life will be exposed to natural radiation. Natural radiation consists of radiation coming from outer space (cosmic radiation), from the ground (terrestrial radiation), as well as internal radiation taken in food containing natural radioactive substances. Natural radiation varies significantly between regions of the earth and in some areas, reaches more than 10 times the average.

Essentially, this radiation affects the body from the outside, but natural radiation is also incorporated into the body through minerals that contain natural radioactivity. This radiation is the considered internal radiation. In our modern civilization we also have to take into account the radiation exposure caused by artificial radiation sources, mostly from medical treatments.

The biological effect of radiation is independent of whether radiation is of natural or artificial origin. What is important is the energy and intensity of the radiation, as well as the time of exposure of certain parts of the body.

1.2 Exposure from External Radiation

a) Natural Radiation
This is general a hard gamma radiation, at an annual average of approximately 30 mrem for cosmic radiation and approximately 50 mrem for terrestrial radiation. In addition the radiation exposure is higher inside buildings than outdoors, caused by natural radiation from building materials. Human beings cannot protect themselves against natural external radiation exposure.

b) Artificial Radiation
The major share of external radiation exposure due to our civilization comes from health care, with an average value of at least 100 mrem per year for the entire population. The remaining radiation exposure - from coal and nuclear power plants, as well as occupational and non-occupational radiation exposure caused by the technical application of radioactive sources, is below 10 mrem per year.

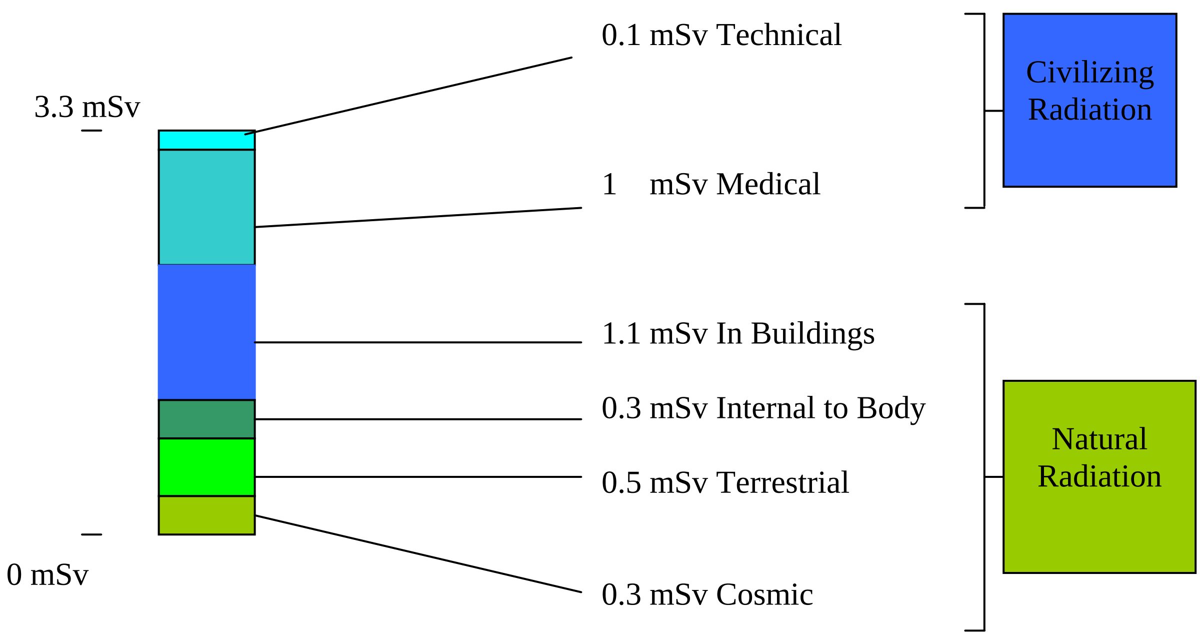
1.3 Internal radiation exposure

a) Natural Radiation
This is a result of various types of radiation, introduced into the human body through food and beverages. The mean effective dose equivalent of radiation exposure caused by the ingestion of naturally occurring radioactive substances is approximately10 mrem per year. It is usually radiation emitted by the isotopes of potassium (K-40) and carbon (C-14).

Another type of internal radiation exposure results from construction materials in buildings emitting radon gas. The most serious effect is on the middle bronchial tubes, with annual average values of approximately 110 mrem. Protection against natural internal radiation exposure is not possible.

b) Artificial Radiation
Internal artificial radiation exposure is possible if nuclear sources cause contamination, which is incorporated into the human body through breathing, eating or wounds. When handling sealed nuclear substances, these hazards do not exist as long as the source capsule is undamaged and the relevant radiation protection regulations are strictly observed.

The diagram below lists the average radiation exposure of the population, given in mSv per year:



AVERAGE RADIATION EXPOSURE PER YEAR Note: 1 mSv = 100 mrem

1.5 Occupationally Exposed Persons

Depending on the degree of occupational exposure, persons working with radioactive material professionally are classified in different categories. The maximum dose rate value in each category recommended by international agencies, is the basis of the Radiation Protection Regulations.

Table of allowed Dose

Classification	A	B	N
Total dose per year (Rem) to whole body, head and trunk	5	1.5	0.5
Total dose per year (Rem) to hands, forearms, feet and ankles	50	15	5

N = not classified people (General Public)
A = classified people category A
B = classified people category B

Persons Not Exposed Occupationally-Category N

The General Public must not be exposed to an annual dose exceeding 0.5 rem (5mSv)

Persons Exposed Occupationally - Category B

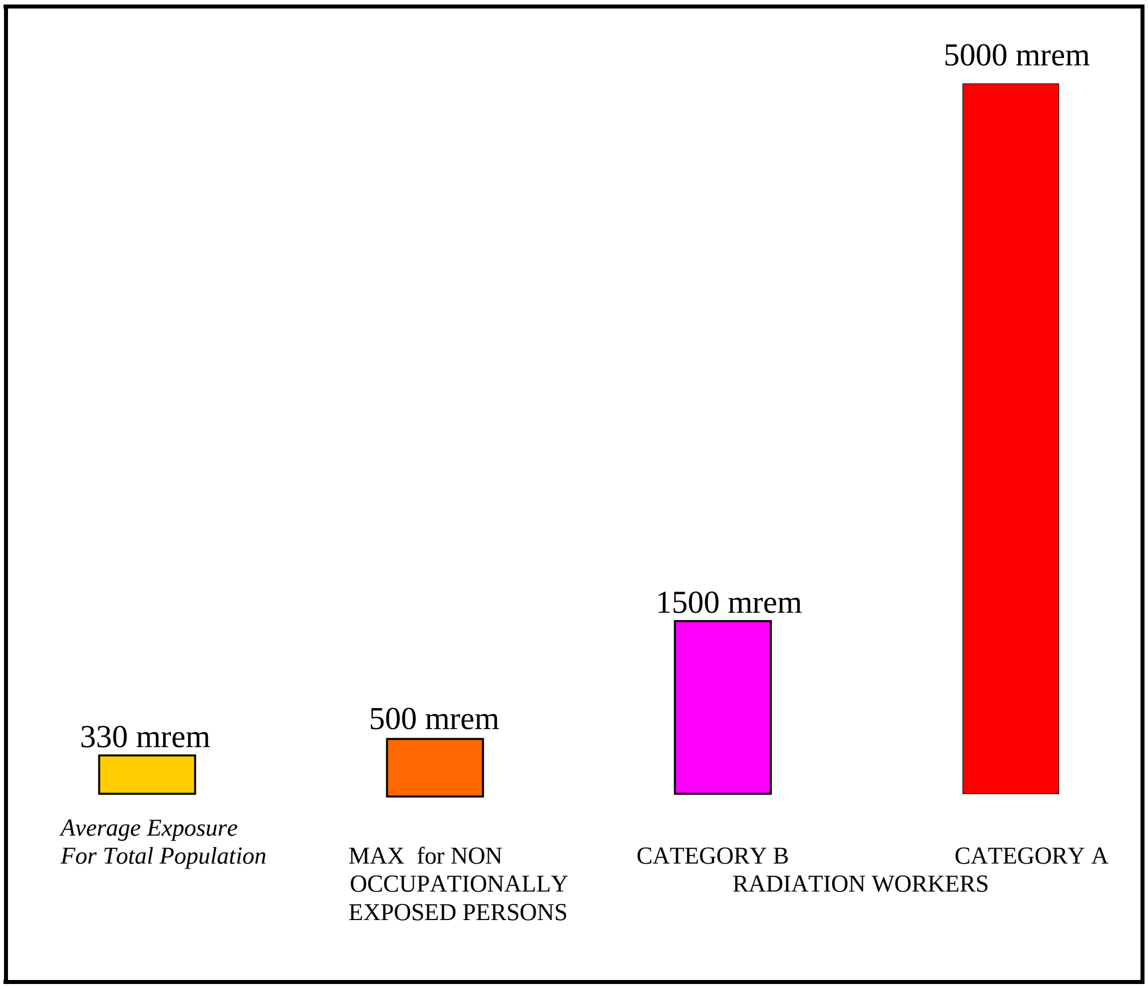
Persons who are exposed to an annual dose of more than 500 mrem but less than 1.5 rem belong to category B. The body doses are recorded but medical examination is only required when handling open (not encapsulated) radioactive sources. Please note that during any quarter the body dose must not exceed fifty percent of the annual dose.

Persons Exposed Occupationally - Category A

Persons who are exposed to an annual dose exceeding 1.5 rem must be classified in category A. The maximum permissible radiation dose for these persons is 5 rem (50 mSV) per annum. The personal doses must be monitored by means of officially approved dosimeters. A medical examination once a year is mandatory. In this case, too, the body dose per quarter must not exceed fifty percent of the annual dose. The total lifetime dose should not exceed 40 rem (400mSv).

Occupationally exposed persons of category A must be examined by an authorized physician; occupationally exposed persons of category B only if they handle open radioactive substances. This examination is repeated once a year. Further employment in the controlled area is only permitted after the physician has granted a certificate of authority.

The diagram below shows the relationship between the average exposure of the population and the additional allowed exposure for persons who handle with radiometric measuring devices occupationally or not occupationally.



MAXIMUM PERMISSIBLE EXPOSURES PER YEAR

2.0 Biological Effects of Radiation

2.1 Dangers of Radiation

When live-tissue is exposed to radiation, chemical and biological processes occur in the individual cells, which may change, damage or destroy the cells, depending on the level of exposure.

Since cells are especially sensitive to radiation during cell division, tissues with a high rate of cell division, e.g. marrow and skin, are especially sensitive to radiation, while other cells which are divided less frequently, e.g. connective tissue and muscles, are less sensitive.

We distinguish between damage occurring in the irradiated organism (somatic radiation damage) and damage to the reproductive cells, which only affect descendants (genetic radiation damage).

2.1.1 Somatic Radiation Damage

This type of damage can only happen as a result of an accident with a high activity source. Such high activity sources are NOT used in our products.

Short-term exposure of the whole body to a high activity source of radiation may cause

- radiation hang-over
- retardation of the blood formation
- inflammatory diseases of the skin
- sterility

The following effects may result when the whole body is exposed to radiation for a short term:

DOSE	EFFECT
up to 0,2 Sv (20,000 m rem)	No effect evident
up to 1 Sv (100 rem)	Slight changes of the blood structure but no damage is likely
1 to 2 Sv (200 rem)	Radiation hang-over, vomiting; serious illness possible; good chance of recuperation
2 to 6 Sv (200-600rem)	Increase in mortality
More than 6 Sv (600 rem)	No chance of survival

Note: 1 rem = 1000 mrem
Permanent exposure to radiation with even distribution causes much less damage, due to the regenerative capacity of living organisms, but may nevertheless lead to chronic illnesses (latent somatic damage), such as leukemia or other kind of cancer. This is also the case if the body is exposed only once to a high dose of radiation.

2.1.2 Genetic Radiation Damage

This is caused by changes in the reproductive cells and can lead to mutations. A lower limit for the probability of mutations cannot be specified. In assessing this limit, however, it is necessary to take into consideration the natural radiation (cosmic and terrestrial radiation) to which human beings are exposed, and which may be quite high in certain areas.

2.1.3 Practical Limits

The acceptable dose rate for handling radioactive sources is specified in the Radiation Protection Regulations at very low levels, set so that the probability of latent somatic damages or additional changes of the genetic material is extremely low.

3.0 Radiation Protection Techniques

3.1 Basic Principles of Radiation Protection

To avoid damage to the human body with near certainty, the maximum annual dose for the persons classified in the different categories has been fixed internationally. (see 1.2)

The aim of radiation protection is to adhere strictly to the specified permissible dose values and furthermore to avoid unnecessary radiation exposure as far as possible, in order to keep the radiation dose for personnel as low as possible.

The formula for calculation of the radiation dose shows what kinds of radiation protections are effective. The radiation dose (D) depends on the activity (A) of the source, its specific gamma radiation constant (k), the distance (a) from the source, the radiation time (T), and the weakening factor (s) of the available shielding.

$$D=Ak\ T/\ a^2s$$

The activity of a source and the corresponding specific gamma radiation constant are determined by the needs of the measuring task. However, when designing a measuring system, the source activity is kept as low as possible by selecting suitable (sensitive) detectors and evaluation instruments.

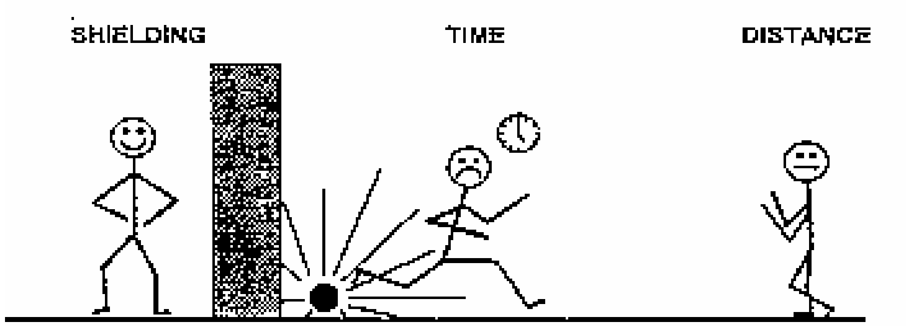
From examination of the above formula, some important basic principles of radiation protection, can be concluded:

Increasing the Distance (a) to the radiation source, i.e. the distance between the source and the body. Since the dose rate follows the inverse square law, doubling the distance means reducing the radiation intensity to a quarter. This is the most efficient as well as the easiest method of radiation protection.
It is effective therefore, to keep the largest distance possible from the device when operating in the proximity of radioactive substances.

Minimizing the Duration of Exposure.
The time (T) has a linear effect and halving the period of exposure gives half the radiation dose. Operations close to the device should be well planned, so that the time of exposure in the immediate vicinity of the source is kept as short as possible.

Use of Shielding Material with a high weakening factor (s), which depends in an exponential function on the product of thickness and density of the shielding material. Typical materials are Lead or Steel. Radioactive sources used in industry are installed in suitable shielding by the manufacturer. These shieldings ensure that dose rates around the device are less than the international allowable limits.

In summary, exposure to radiation depends on:



Attention to these considerations at all times ensures that persons working with radiometric devices are exposed As Low As Reasonably Attainable (ALARA) doses of radiation.

4.0 General Rules of Behavior

Basically the Radiation Protection Regulations must be observed, which stipulate that Unnecessary exposure to radiation must be avoided. For each installation the user must abide by rules of behavior which ensure safe operation and maintenance of the equipment. Several aspects of these rules are mandatory and stipulated by the US Nuclear Regulatory Commission or Agreement State.

When formulating such rules, the following must be considered and understood:

- Installation, Assembly and Disassembly, who is authorized, who is not
- Operations in the immediate proximity of the shielding.
- Periodic maintenance, Shutter Tests, Leak Tests
- Responsibility for the key of the lock of the shielding container.

Note: Shutter mechanisms of shielding containers may NOT be LOCKED in the OPEN position. This is a condition stipulated by the NRC and the Agreement State.

- Accident Procedures
- Reporting and Documentation Responsibilities
- Operator Training

4.1 Periodic Leak Tests

Depending on the specific conditions stipulated in the Registration for the device to be installed, you are required to ensure that a radiation leak test for the device is performed within the stipulated times. These are either 6 months or 3 years. The Radiation Safety Officer (RSO) of Berthold Technologies must be provided with copies of the documentation relating to the leak test. Berthold Technologies will provide this service at the request of the user.

4.2 Shutter Test

Every 6 months, you are required to formally ensure that the shutter for turning off the active radiation beam is operational and operating correctly. You must document this activity and provide copies of the documents to the RSO of Berthold Technologies U.S.A., LLC. The documents at your site must be available to an Agreement State or NRC inspector, should he/she request to see them. Instructions for performing such a test are provided in the service section of your Operator's Manual for the system.

4. 3 Relocation

Unless you are Specifically Licensed by an Agreement State or NRC to do so, you may not remove or relocate the shielding containing the source.

4.4 Modification

You may NOT in any way modify, alter or change the shielding containing the source. You may NOT remove the source from the shielding.

4.5 Labeling

It is a condition of the registration and the license to operate the system, that labels on the device are maintained in a legible condition and not removed from the device. Replacement labels are readily available from Berthold Technologies U.S.A.

4.6 Accidents, Loss, Damage, Fire, Theft

Remember the principles of health and safety in such situations: Time, Distance, and Shielding. In the event of the aforementioned situations,

1.**Limit access** to the area

2. **Report to the RSO** (Berthold Technologies U.S.A.) who will advise what further immediate precautions to take and arrange for quick support from a licensed person.

3.In the case of loss or theft, **notify the regulatory authority for your State**. A list is included with your copy of the regulations.

4. **If the sealed radioactive substances are no longer contained in their shielding, the supervisory authority must be notified immediately and steps taken to ensure that the contamination cannot be dispersed**. Proper handling and disposal of possibly leaking sources or contaminated parts of the equipment must be coordinated with the supervisory authority.

4.7 Source Disposal

At the end of their useful life, sources must removed by properly licensed, qualified and trained persons and returned to the original manufacturer.

If you have questions relating to the operation or health and safety considerations, please do not hesitate to contact us at Berthold Technologies U.S.A., LLC.

Fax Number 865 425 4309   Telephone 865 483 1488.

5 Radiation Exposure From an Industrial Gamma Gauge

5.1 Level Gauge

To better understand the difference in radiation exposure received in the normal course of living on this planet with radiation exposure from an accidental exposure from an industrial gamma gauge we must first explore the radiation received during an "exposure incident".

Accidental exposure from a continuous level industrial gauge normally will yield the highest short term exposure. A typical activity and isotope is a 100mCi Cs 137 point source used to measure level in a 10 foot diameter vessel with ½ inch steel walls and 3 inches of thermal insulation. If the source shutter is not closed before the vessel is entered and an individual is in the center of the vessel and in the beam path the dose to the body can be easily calculated. The radiation field in the center of the vessel is 5 millirem per hour and if the body was in the beam path for one hour the body dose would be 5 millirems. (A similar exposure analysis could be made for a Co60 rod or point source).

This radiation exposure would not cause radiation hang over, a slight change in blood structure, or show any effect. The body dose threshold that will cause an effect to the body is 20,000 mrem. In this cased the body would receive an additional 5 millirem dose which would be added to 330 mrem (see table on Page 7), which is the average body dose for the general population per year. This increase in body dose would be insignificant.

In general the additional exposure from industrial gamma gauges is a very small part of a person's total radiation exposure in a year from natural causes.

5.2 Exposure from a Pipe Mounted Density Gauge

Since the source within the lead shield in mounted directly on a pipe which normally has a diameter of less than 20 inches it is virtually impossible for an individual to get between the source and the detector. However if a person occupies the space behind the source shield, exposure does exist. If we assume the worker spends 4 hours per week (one half day) 12 inches from our point source shield which is loaded with 50 mCi of Cs 137, the body is calculated as follows:
Assuming our standard lead shielding, the model LB-7440, the strength of the radiation field would be 0.5 mrem per hour. Based on spending 4 hours per week, 50 weeks of the year **within 12 inches from the back of the shielding,** it can be determined that the worker would receive a dose of 100 mrem per year. Here again the additional 100 mrem would be added the workers normal average yearly dose of 330 mrem per year from natural sources and the total yearly body dose of 430 mrem is far below any damaging radiation exposure. (See table 5.3)

5.3 Results of Radiation Exposure

BODY DOSE	EFFECT TO THE INDIVIDUAL
Level exposure of 5 mrem / yr.	No noticeable effect
Density exposure 100mrem / yr.	No noticeable effect
Average exposure of population, (environmental, medical etc) 330 mrem / yr.	No noticeable effect
up to 20,000mrem in a few days	No effect evident
up to 100,000mrem in a few days	Slight changes of the blood structure but no damage is likely
Up to 200,000mrem in a few days	Radiation hang-over, vomiting; serious illness possible; good chance of recuperation
Up to 600,000mrem in a few days	Increase in mortality
Over 600,000 mrem in a few days	No chance of survival

Note: See also Table on Page 8.

5.4 Conclusion

From the above information, it may be concluded that the proper and intelligent use of Radiometric Gauges of all types leads to extremely small doses rates in areas populated by persons. The resulting annual doses are significantly smaller than the average annual doses to the population caused by natural causes and the total dose is very far below that which causes detrimental effects to health. For further information on this subject, please contact us at 865 483 1488 or the US Nuclear Regulatory Commission at http://www.hsrd.ornl.gov/nrc/

We are happy that you have taken an interest in nuclear safety and the technologies in which they are used. We are happy to answer specific questions on any of our product and how they apply to your safety concerns!