6 International Safety Standards for Radiation Protection

"Insisting on perfect safety is for people who don't have the balls to live in the real world."

Mary Shafer

safety standards
European Directive
dose limits
exemption levels
clearance levels

The International Commission on Radiological Protection (ICRP) has proposed safety standards to protect the health of workers and the general public against the dangers arising from ionizing radiation. The recommendations are laid down in a European Directive (Council Directive 96/29/EURATOM) which was presented to the Member States of the European Community. The report requested the different countries to integrate the proposed dose limits, exemption levels, clearance levels, and, in general, the regulations of the European Directive into national law so that compliance with the basic standards is ensured. The recommended limits contained in the directive must be respected, even though the national regulations are allowed to impose more stringent levels, but there is no room for allowing higher, more generous levels.

European countries have completed this integration into national law over a period of several years, e.g. Germany published the radiation-protection regulations in 2001, and France followed in 2003. The regulations in different countries are not completely identical, but the guidelines are the same all over Europe.

American Directive

In contrast, other countries, e.g. the United States of America, have regulations which differ distinctly from the European Directive. For example, the annual whole-body dose limit for workers exposed to ionizing radiation in the US is 50 mSv compared to 20 mSv in European countries. Other differences are that in the US the old radiation units (rad and rem) are still in use (1 Sv = 100 rem, 1 Gy = 100 rad).

In the following the main features of the European directive are presented, which should cover essentially all European countries, and after that the regulations of the United States and other countries will be described. The limits given in the main body of this book are based on the regulations of the European Directive and the recommendations of the International Commission on Radiological Protection (ICRP, `www.icrp.org/`).

C. Grupen, *Introduction to Radiation Protection*,
Graduate Texts in Physics, DOI 10.1007/978-3-642-02586-0_6,
© Springer-Verlag Berlin Heidelberg 2010

6.1 European Directive

The guidelines of the European Directive are intended to:

- respect the maximum permissible doses compatible with adequate safety;
- respect the maximum levels of exposure and contamination;
- consider the fundamental principles governing the health surveillance of workers.

The Directive has defined safety standards in the following way:

- the limit on the effective dose for exposed workers is 100 mSv in a consecutive five-year period, subject to a maximum effective dose of 50 mSv in any single year. In accordance with this, most Member States have defined an annual limit of 20 mSv.
- the annual limit on the equivalent dose for the lens of the eye is 150 mSv.
- the annual limit on the equivalent dose for the skin is 500 mSv.
- the annual limit on the equivalent dose for the hands, forearms, feet, and ankles is 500 mSv.

annual limit 20 mSv in the EU

Under exceptional circumstances, excluding radiological emergencies, occupational doses for some identified workers may exceed the annual dose limits above, provided that such exposures are limited in time and confined to certain working areas. The maximum exposure as defined for the five-year period must, however, be respected.

emergency situations

The dose limits for apprentices and students aged 18 or over are identical to the ones mentioned. However, the dose limits for apprentices and students aged between 16 and 18 are reduced to 6 mSv per year for the whole-body dose. Correspondingly, the dose limits for this age group is also lower for the eyes (50 mSv/yr), the skin (150 mSv/yr), and hands (150 mSv/yr).

apprentices and students

For the general public the annual dose limit is 1 mSv. In special circumstances a higher effective dose may be authorized in a single year, provided that the average over five consecutive years does not exceed 1 mSv per year. Correspondingly, the annual limit for the eyes for the general public is 15 mSv/yr and 50 mSv/yr for the skin.

annual dose limit 1 mSv for the public

The general recommendation is that reasonable steps must be taken to ensure that the exposure of the population as a whole is kept as low as reasonably achievable (ALARA principle). This last recommendation has been restricted, e.g. in Germany, to keep the level as low as possible.

ALARA principle

In the framework of formulating the fundamental principles governing the operational protection of exposed workers, 'controlled areas' and 'supervised areas' or 'surveyed areas' areas are defined.

controlled area
surveyed area

Controlled areas must be delineated and access to the area shall be restricted to individuals who have received appropriate instructions on radiation-protection standards. For supervised areas the restrictions are less severe, and the potential exposures are expected to be smaller. However, radiological surveillance of the working environment must be organized in accordance with the provisions of the standards of radiation protection.

exclusion area

In addition to surveyed areas ($\leq$ 6 mSv/yr) and controlled areas ($\leq$ 20 mSv/yr) also 'exclusion areas' ($\leq$ 3 mSv/h) are defined. Admittance to exclusion areas is only permitted for exceptional radiological situations, like e.g. radiation accidents.

category-A workers

category-B workers

For the purposes of monitoring and surveillance a distinction of exposed workers into two categories is made. Category-A workers are those who are liable to receive an effective dose greater than 6 mSv per year or equivalent doses greater than 3/10 of the dose limits for the lens of the eye, skin, and extremities as defined above (just as 6 mSv is 3/10 of the annual dose limit (20 mSv) for exposed workers). Category-B workers are those working in areas where there is the possibility to be exposed to ionizing radiation in excess of an annual dose of 1 mSv. The actually received doses must be individually monitored by an appropriate dosimetric service. It also has to be demonstrated that category-B workers are correctly classified. In case of accidental exposure the relevant doses and their distribution in the body shall be assessed.

The exposures have to be documented and retained during the working life involving exposure to ionizing radiation of the exposed workers, and afterwards until the individual has or would have attained an age of 75 years, but in any case not less than 30 years from the termination of the work involving exposure.

students and apprentices

The exposure conditions and operational protection of students and apprentices aged 18 or over are equivalent to those of exposed workers of category A or B. Students and apprentices aged between 16 and 18 years shall be treated equivalently as category-B workers only (i.e., their possible annual doses are restricted to a range of 1 mSv to 6 mSv).

medical surveillance

The medical surveillance of category-A workers lies in the responsibility of approved medical practitioners or approved occupational health services. This medical surveillance includes a medical examination prior to employment or classification as a category-A worker. The purpose of this thorough examination is to determine the worker's fitness for a position as category-A worker. The medical fitness must be periodically reviewed, at least once a year.

The European Directive closes with asking the Member States of the European Community to bring into force the laws, regulations and administrative provisions necessary to comply with this Directive before 13 May 2000. No European country was able to implement the Directive within this time limit. The Member States were given a certain freedom to implement the Directive, with the following constraint: If a Member State is to adopt dose limits which are stricter than those laid down in the Directive, it shall inform the Commission and the other Member States of its regulations. It is, however, not permitted to adopt more liberal dose limits.

exemption limits

Amongst appendices to the Directive exemption limits for the quantity or activity concentration of radioisotopes are defined. The European Commission has also published guidance on the clearance levels of building material arising e.g. from the dismantling of nuclear installations. Furthermore, the European Commission has introduced the concept of general clearance levels (in activity per unit mass): default values, for materials arising from any practice, any type of material, and any pathway of recycling or reuse.[1] The "Guidance on General Clearance Levels for Practices" contains a wealth of information on all conceivable radiation risks and exposures presented in the form of detailed tables with explanations. It covers man-made radiation equipment as well as natural sources (e.g. radon exposures).

clearance levels

6.2 American Directive

The American regulations on radiation protection are laid down in the 'Code of Federal Regulations' issued by the 'National Archives and Records Administration' available from the 'United States Government Printing Office'. Under 'Title 10: Energy' the 'Occupational Radiation Protection' regulations are defined for the Department of Energy in the document called '10CFR 835'. In the following the main items of the regulations, taken from the 'Code of Federal Regulations', are sketched in abridged form.

occupational dose limits

The occupational dose limits for general employees shall be controlled such that the following limits are not exceeded in a year:

- a total effective dose equivalent of 5 rems (50 mSv);
- the sum of the deep dose equivalent for external exposures and the committed dose equivalent to any organ or tissue other than the lens of the eye of 50 rems (500 mSv);

[1] Practical Use of the Concepts of Clearance and Exemption; Part I: Guidance on General Clearance Levels for Practices; Part II: Application of the Concepts of Exemption and Clearance to Natural Radiation Sources; Recommendations of the Group of Experts established under the terms of Article 31 of the European Treaty.

- a lens-of-the-eye dose equivalent of 15 rems (150 mSv); and
- a shallow dose equivalent of 50 rems (500 mSv) to the skin or to any extremity.

annual dose limit 50 mSv USA

All occupational doses received during the current year, except doses resulting from planned special exposures and emergency exposures shall be included when demonstrating compliance with the above limits. Doses from background, therapeutic and diagnostic medical radiation, and participation as a subject in medical research programs shall not be included in dose records or in the assessment of compliance with the occupational dose limits.

standard weighting factor

radiation weighting factor

tissue weighting factor

The total effective dose equivalent during a year shall be determined by summing the effective dose equivalent from external exposures and the committed effective dose equivalent from intakes during the year. Determinations of the effective dose equivalent shall be made using the standard-weighting-factor values as provided by the regulations (10CFR 835.2 Definitions). The radiation and tissue weighting factors in the US regulations (see the following tables) are very similar, but not identical, to those of the European Directive which are given in the main body of the book.

Table 6.1
US quality factors (‘radiation weighting factors’)

radiation type	**quality factor**
X rays, gamma rays, positrons, electrons	1
neutrons, less than 10 keV	3
neutrons, over 10 keV	10
protons and singly charged particles of unknown energy with rest mass greater than one atomic mass unit	10
alpha particles and multiply charged particles (and particles of unknown charge) of unknown energy	20

Table 6.2
US weighting factors for various organs and tissues

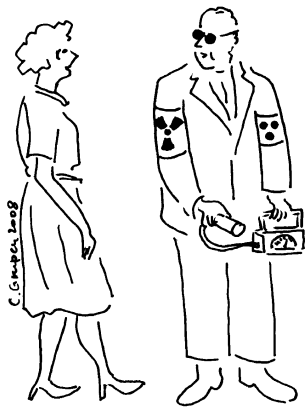
organs or tissues	**weighting factor**
gonads	0.25
breasts	0.15
red bone marrow	0.12
lungs	0.12
thyroid gland	0.03
periosteum, bone surface	0.03
other organs or tissue	0.30
whole body	1.00

planned special exposures

For planned special exposures the following conditions must be fulfilled:

- A planned special exposure may be authorized for a radiological worker to receive doses in addition to and accounted for separately from the doses received under the limits specified above, provided that each of the following conditions is satisfied:
  * the planned special exposure is considered only in an exceptional situation when alternatives that might prevent a radiological worker from exceeding the standard limits are unavailable or impractical;
  * the contractor management or employer specifically requests the planned special exposure, in writing; and
  * joint written approval is received from the appropriate DOE Headquarters program office and the Secretarial Officer responsible for environment, safety, and health matters.

radiological worker



"I should have known that handling too many radioactive sources can cause a cataract!"

© by Claus Grupen

- Prior to requesting an individual to participate in an authorized planned special exposure, the individual's dose from all previous planned special exposures and all doses in excess of the occupational dose limits shall be determined.
- An individual shall not receive a planned special exposure that, in addition to the doses determined above, would result in a dose exceeding the following:
  * in a year a value of 5 rem (50 mSv); and
  * over the individual's lifetime, five times the numerical values of the dose limits established for radiation workers (i.e. it should not exceed 25 rem (250 mSv)).
- Prior to a planned special exposure, written consent shall be obtained from each individual involved. Each such written consent shall include:
  * the purpose of the planned operations and procedures to be used;
  * the estimated doses and associated potential risks and specific radiological conditions and other hazards which might be involved in performing the task; and
  * instructions on the measures to be taken to keep the dose ALARA considering other risks that may be present.

ALARA principle

- Records of the conduct of a planned special exposure shall be maintained and a written report submitted within 30 days after the planned special exposure to the approving organizations.
- The dose from planned special exposures is not to be considered in controlling future occupational doses of the individual, but is to be included in records and reports.

limits for the embryo/fetus

Limits for the embryo/fetus are regulated along the following conditions:

- The dose-equivalent limit for the embryo/fetus from the period of conception to birth, as a result of occupational exposure of a declared pregnant worker, is 0.5 rem (5 mSv).
- Substantial variation above a uniform exposure rate should be avoided.
- If the dose equivalent to the embryo/fetus is determined to have already exceeded 0.5 rem (5 mSv) by the time a worker declares her pregnancy, the declared pregnant worker shall not be assigned to tasks where additional occupational exposure is likely during the remaining gestation period.

pregnancy

Specific occupational dose limits for minors are defined as:

- The dose-equivalent limits for minors occupationally exposed to radiation and/or radioactive materials at a DOE activity are 0.1 rem (1 mSv) total effective dose equivalent in a year, 1.5 rem (15 mSv) for the lens of the eye, and 5 rem (50 mSv) for the skin.

limits for the public

Furthermore, limits for members of the public entering a controlled area are defined in the following way:

- The total effective dose-equivalent limit for members of the public exposed to radiation and/or radioactive material during access to a controlled area is 0.1 rem (1 mSv) in a year.

monitoring and surveillance

The American Directive also regulates the following general requirements concerning technical aspects of monitoring and surveillance:

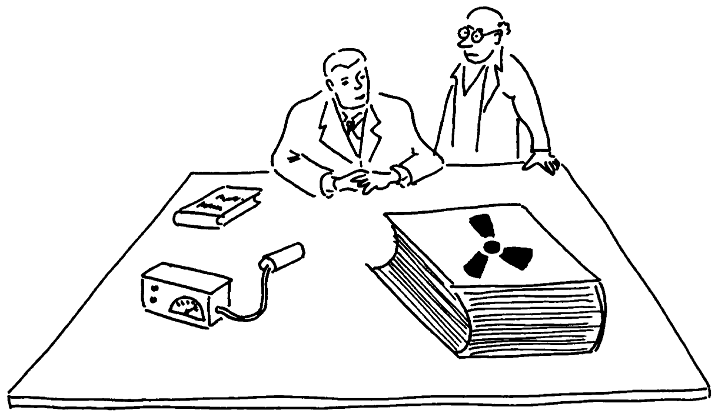
- Monitoring of individuals and areas shall be performed to:
  * demonstrate compliance with the regulations in this part;
  * document radiological conditions;
  * detect changes in radiological conditions;
  * detect the gradual buildup of radioactive material;
  * verify the effectiveness of engineering and process controls in containing radioactive material and reducing radiation exposure; and
  * identify and control potential sources of individual exposure to radiation and/or radioactive material.
- Instruments and equipment used for monitoring shall be:
  * periodically maintained and calibrated on an established frequency;
  * appropriate for the type(s), levels, and energies of the radiation(s) encountered;
  * appropriate for existing environmental conditions; and
  * routinely tested for operability.

The regulations define also special radiological areas:

- Within high- and very-high-radiation areas: **radiation areas**
  * The following measures shall be implemented for each entry into a high-radiation area:
    * The area shall be monitored as necessary during access to determine the exposure rates to which the individuals are exposed.
    * Each individual shall be monitored by a supplemental dosimetry device or other means capable of providing an immediate estimate of the individual's integrated deep dose equivalent during the entry. **supplemental dosimetry device**
- Within controlled areas: **controlled areas**
  * Each access point to a controlled area shall be posted whenever radiological areas or radioactive-material areas exist in the area.
  * Individuals who enter only controlled areas without entering radiological areas or radioactive-material areas are not expected to receive a total effective dose equivalent of more than 0.1 rem (1 mSv) in a year.
  * Signs used for this purpose may be selected by the contractor to avoid conflict with local security requirements.
- Within radiological areas and radioactive-material areas: **radiological areas**
  * Radiological areas and radioactive-material areas are divided into the following categories and should be posted with conspicuous signs bearing the wording:
  * Radiation area. The words "Caution, Radiation Area" shall be posted at each radiation area. **radiation areas**
  * High-radiation area. The words "Caution, High Radiation Area" or "Danger, High Radiation Area" shall be posted at each high-radiation area.
  * Very-high-radiation area. The words "Grave Danger, Very High Radiation Area" shall be posted at each very-high-radiation area.
  * Airborne radioactivity area. The words "Caution, Airborne Radioactivity Area" or "Danger, Airborne Radioactivity Area" shall be posted at each airborne radioactivity area. **airborne activity**
  * Contamination area. The words "Caution, Contamination Area" shall be posted at each contamination area. **contamination area**
  * High-contamination area. The words "Caution, High Contamination Area" or "Danger, High Contamination Area" shall be posted at each high-contamination area.
  * Radioactive-material area. The words "Caution, Radioactive Material(s)" shall be posted at each radioactive-material area.

nuclear accident dosimetry

It must be remembered that the effective US dose units are given in rem, and the US activities are given in curie (Ci). Also the old unit 'roentgen' is still in use. In a very detailed annex to the US regulations (under the item 'Nuclear accident dosimetry') limits on activity and concentration of radioisotopes in air are given in a similar way as in the European Directive.



"Our new radiation-protection manual!" © by Claus Grupen

6.3 Other Countries

6.3.1 Australia

The Australian Radiation Protection and Nuclear Safety Regulations have been published 1999 as Statutory Rules under `www.comlaw.gov.au/ComLaw/Legislation/LegislativeInstrumentCompilation1.nsf/0/2E2B83BDE995DE10CA256F71004F21F6/$file/AusRadProtNucSafe1999.pdf`. The regulations are laid down in a very detailed document.

main dose limits

The main dose limits are:

* The effective dose limit for occupational exposures is 20 mSv annually, averaged over 5 consecutive calendar years.
* However, the effective dose for a person subject to occupational exposure must not, in any year, be greater than 50 mSv.
* The effective dose limit for public exposure is 1 mSv annually.
* The effective dose limit for an unborn child is to be consistent with the effective dose limit for public exposure.

The limits for the partial-body doses are defined as:

limits for partial-body doses

* The annual equivalent-dose limit for the lens of the eye is 150 mSv for occupational exposure and 15 mSv for public exposure.
* For occupational exposure, the annual equivalent-dose limit to the hands and feet is 500 mSv.
* The annual equivalent-dose limit to the skin is 500 mSv for occupational exposure and 50 mSv for public exposure. The annual equivalent-dose limit to the skin applies to the average dose received by any 1 cm^2 of skin.

The maximum annual dose measured at the center of Australia's nuclear science capabilities and expertise site ANSTO (Australian Nuclear Science and Technology Organisation) was in one case 65.9 mSv which exceeded the annual dose limit of 50 mSv for one year. The worker exposed to this high-level radiation was removed from the radiation work for the remainder of the year. Typical effective doses at this site are, however, around 1 mSv/yr and maximum effective doses around 10 mSv/yr.

ANSTO

The ARPANS (Australian Radiation Protection and Nuclear Safety) regulations prescribe the need for emergency plans. The Regulatory Assessments Principles address the various aspects for emergency plans, procedures, and preparedness to be assessed. These rules are laid down in the Regulatory Assessments Principles.

ARPANS

In a detailed appendix exemption limits for all radioisotopes are given. The Australian regulations also contains rules for non-ionizing radiation.

6.3.2 Brazil[2]

The general dose limits in Brazil as given by the document CNEN NE 3.01 (`http://cfhr.epm.br/download/aulas/fisica/Limites__Doses.pdf`) are:

general dose limits

* The effective dose limit for radiation-exposed workers is 20 mSv /yr. For five consecutive years the total effective dose is limited to 100 mSv. It must not exceed 50 mSv/yr in any year of this period. According to the Brazilian regulations a dose of 50 mSv corresponds to a stochastic lethal cancer risk of 5×10^{-4}. This value

radiation-exposed workers

[2] I thank Prof. Dra. Simone Coutinho Cardoso, Instituto de Física, Universidade Federal do Rio de Janeiro, Laboratório de Física da Radiação Gama, Rio de Janeiro, Prof. Dr. Fernando Marroquim Leao de Almeida Jr., Instituto de Física, Universidade Federal do Rio de Janeiro, Ilha do Fundão, Rio de Janeiro, and Prof. Dra. Regina Bitelli Medeiros, Universidade Federal de São Paulo, Coordenadora do Núcleo de Proteção Radiológica, for helping me with the interpretation of the Brazilian radiation-protection regulations.

corresponds to a risk factor of 1% per sievert, which is lower by a factor of 5 compared to the risk factor as given by the ICRP.

* For radiation-exposed workers the limit on the annual dose equivalent to extremities or the skin is 500 mSv; the dose limit for the lens of the eye is 150 mSv.

women

* The abdomen dose limit for women in childbearing years should not exceed 10 mSv in a period of three consecutive months.

pregnancy

* For pregnant women working in radiation areas their activities must be controlled and, if necessary, restricted in such a way that it is improbable, from the moment of the notification of the pregnancy, that the fetus receives more that 1 mSv during the remaining portion of the period of gestation.

students or apprentices

* Students or apprentices over 18 should not get more than 10% of the limits for radiation-exposed workers in a single exposure.

individuals under 18

* Individuals under 18 are not supposed to be exposed to radiation (except, of course, for environmental radiation).

general public

* The annual whole-body dose limit for members of the general public is 1 mSv. In exceptional circumstances an annual dose limit of 5 mSv may be agreed to by the authorities if the average over a five-year period does not exceed 1 mSv/yr. The limits for the lens of the eye is 15 mSv/yr and those for the skin is 50 mSv/yr for the general public. The annual dose limit for any organ or tissue is 1 mSv divided by the corresponding organ or tissue weighting factor.

Depending on the contamination of work places different categories are defined. In general the limits on contaminations of work surfaces are more stringent by a factor of 10 for α emitters compared to β radiation.

6.3.3 Canada

whole-body dose limits

The Canadian radiation-protection regulations are laid down by the Canadian Nuclear Safety Commission under `http://canadagazette.gc.ca/partII/2000/20000621/html/sor203-e.html`. The main whole-body dose limits are given by:

nuclear-energy worker

* for a nuclear-energy worker: 50 mSv for a one-year dosimetry period and 100 mSv for a five-year dosimetry period;

pregnancy

* for a pregnant nuclear-energy worker: 4 mSv. This dose should not exhibit strong exposure peaks (within the limits of ≤ 4 mSv), but it should rather be balanced over the gestation period;

general public

* for a person who is not a nuclear-energy worker (i.e. general public) the annual dose limit is 1 mSv.

Special limits are defined as follows: **special limits**

* for a nuclear-energy worker the annual limits for the lens of the eye is 150 mSv, for the skin 500 mSv, and hands and feet 500 mSv; **nuclear-energy worker**
* for any other person the corresponding limits are: lens of the eye (15 mSv), skin (50 mSv), and hands and feet (50 mSv). **other persons**

During the control of an emergency and the consequent immediate and urgent remedial work, the effective dose and the equivalent dose may exceed the applicable dose limits as given above, but the effective dose shall not exceed 500 mSv and the equivalent dose received by the skin shall not exceed 5000 mSv. When a licensee becomes aware that a dose of radiation received by and committed to a person or an organ or tissue may have exceeded the dose limit as given above, the licensee shall

emergency and remedial work

actions in case of exceeded dose limits

* immediately notify the person and the radiation commission of the dose;
* require the person to leave any work that is likely to add to the dose;
* conduct an investigation to determine the magnitude of the dose and to establish the causes of the exposure;
* identify and take any action required to prevent the occurrence of a similar incident; and
* within 21 days after becoming aware that the dose limit has been exceeded, report to the radiation commission the results of the investigation or on the progress that has been made in conducting the investigation.

The organ or tissue weighting factors and radiation weighting factors are those as recommended by the ICRP as given in Chap. 2.

6.3.4 China[3]

China has adopted all ICRP and ICRU regulations/recommendations.

6.3.5 India

The Atomic Energy Regulatory Board (AERB) in India has defined the rules for radiation protection in the Atomic Energy Act. A comprehensive paper describing the regulations in India is given in S.B. Grover, J. Kumar, A. Gupta, and L. Khanna “Protection against radiation hazards: Regulatory bodies, safety norms, dose limits and **AERB**

[3] I thank Prof. Dr. Yuanning Gao form the Centre for High Energy Physics, Tsinghua University, Beijing, China, for providing this information.

protection devices", published in the Indian Journal of Radiology and Imaging (Volume 12, Issue No. 2, 2002). The rules are very similar to other countries.

general principles

The radiation-protection standards are based on three general principles:

* Justification of a practice, i.e., no practice involving exposures to radiation should be adopted unless it provides sufficient benefit to offset the detrimental effects of radiation.
* Protection should be optimized in relation to the magnitude of doses and number of people exposed.
* Dose limitation deals with the idea of establishing annual dose limits for occupational exposures, public exposures, and exposures to the embryo and fetus.

radiation-exposed workers

The main annual dose limits are:

* for radiation-exposed workers: 30 mSv/yr and 100 mSv for a five-year period;
* for radiation-exposed workers: 150 mSv/yr for the lens of the eye and 500 mSv/yr for the skin, hands, and feet;
* for the public: 1 mSv/yr.

More details can be found on the web page of the Atomic Energy Regulatory Board of India `www.aerb.gov.in/`.

6.3.6 Japan[4]

dose limit for 5 years

The general dose limits are:

women

pregnancy

* 100 mSv/5 years with a maximum of 50 mSv per single year. The same dose limit applies for women with the additional constraint of 5 mSv/3 months.
* Exceptions for women who are pregnant: 1 mSv due to internal exposure (from the moment when the employer knows of the pregnancy).

modified rules for large installations

For large nuclear physics and particle physics installations these general rules can be modified. For the large High Energy accelerator research organization KEK at Tsukuba the following regulations apply:

[4] I am grateful to Dr. Syuichi Ban from the High Energy Accelerator Research Organisation KEK in Tsukuba, Japan, for providing this information; see also his presentation "Personnel exposure control in KEK" given at the "Workshop on Operational Radiation Protection at High-Energy Accelerators"; `http://proj-orpw05.web.cern.ch/proj-orpw05/`.

* dose limit for man 20 mSv/year,
* dose limit for woman 6 mSv/year,

with the necessity to record the exposures

recording

* if the gamma dose exceeds 0.1 mSv/month,
* if the neutron dose exceeds 0.2 mSv/month.

Further constraints for the working levels for daily and weekly control are defined such that

working levels

* daily control level for man 0.5 mSv/day,
* daily control level for woman 0.3 mSv/day,
* weekly control level for man 1.0 mSv/week,
* weekly control level for woman 0.5 mSv/week.

It is remarkable that the dose limits are different for women and men.

If exposures larger than 7 mSv/yr are recorded, the reason must be found, and the fact must be reported to the radiation safety supervisor.

6.3.7 Mexico[5]

The regulations in Mexico are to a certain extent similar to the ones defined in the US, but in some cases much more liberal. They are written down in `www.cnsns.gob.mx/radiolo/reglamentos/rgsrweb.htm`. The dose limits are given in sievert and in rem and the units of activity are given both in becquerel and in curie. For ion doses even the unit 'roentgen' is in use.

The general limit for the annual whole-body dose for radiation-exposed workers is 50 mSv (5 rem), and the limit for the lens of the eye is 150 mSv (15 rem). The regulation differentiates between stochastic and non-stochastic doses. The annual limit for stochastic doses is given above, but for non-stochastic doses the limit is 500 mSv (50 rem) with the exception for the lens of the eye, which is still 150 mSv (15 rem).

radiation-exposed workers

Young people aged between 16 and 18 are not supposed to work in radiation areas. However, if education e.g. for students, requires the handling of radioactive material, an annual limit for the whole body of 15 mSv (1.5 rem) applies. The annual dose limit for the general public is 1 mSv (0.1 rem).

young people

general public

To handle emergency situations, e.g. preventing the risk of fire or contamination of valuable equipment, a singular dose up to 250 mSv

emergency situations

[5] I am grateful to Prof. Dr. Jürgen Engelfried, Universidad Autonoma de San Luis Potosi, Mexico, for providing this information.

(25 rem) is acceptable. For the hands or the forearm even 1 Sv (100 rem) can be tolerated in such a situation. In case of severe accidents all necessary steps must be taken to mitigate danger to life and health, and to prevent exposure of many workers to high-level radiation. Under these exceptional circumstances even doses of up to 1 Sv (100 rem) for the whole body and for hands and forearms of 3 Sv (300 rem) are permitted. It is also recommended that persons exposed to high-level radiation in a radiation accident should not father a child within six months after having received a high dose.

singular doses

Furthermore, it is recommended that for women in childbearing years a possible exposure to radiation should be evenly distributed in time. This also applies for pregnant women with the additional recommendation that the probability to receive a dose of more than 15 mSv (1.5 rem) should be very small.

pregnancy

In analogy to the US and Europe also different radiation areas are defined. A 'radiation area' is a zone where a dose rate of more than 0.05 mSv/h (5 mrem/h) can occur or a dose of more than 1 mSv (100 mrem) in five consecutive days might be received. In a 'high-radiation area' exposures of more than 1 mSv/h (100 mrem/h) are possible. Special precautions have to be taken for areas where gaseous radioactive substances are handled to limit the intake of radioactive material into the body.

radiation area

6.3.8 Russia[6]

Russia has also adopted the general framework of the ICRP and ICRU regulations/recommendations. The limit on the equivalent dose is 20 mSv per year on the average during any five consecutive years, but not larger than 50 mSv per year. For the normal population the limit is 1 mSv/yr on average during any five consecutive years, but less than 5 mSv in any single year.

normal population

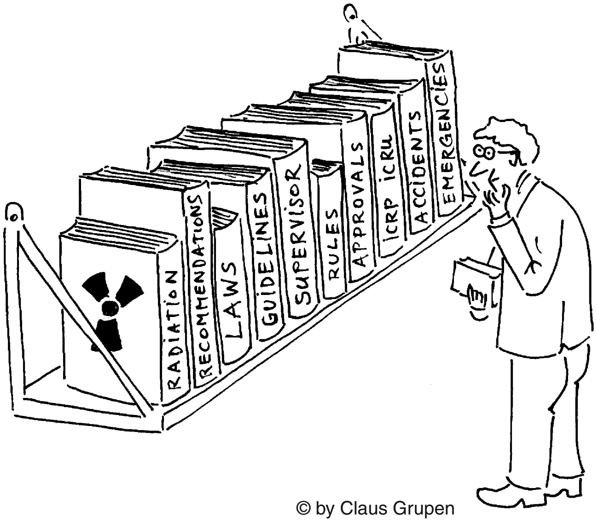
For women below the age of 45, working with radiation sources, there are additional requirements: a dose on the surface of the lower part of the belly should be less than 1 mSv/month and the total amount of radionuclides entering the organism should be $< 1/20$ of that for male personnel. Under these conditions the dose of a possible fetus irradiation is < 1 mSv during two months of unregistered pregnancy.

possible fetus irradiation

pregnant women

Pregnant women, starting from the day when a woman claims pregnancy, should be moved to a job not related to radiation sources or radiation exposures for the whole period of pregnancy and feeding.

[6] I am grateful to Prof. Dr. Simon Eidelman, Budker Institute of Nuclear Physics, Novosibirsk, Russia, and to Prof. Dr. Gerd Beyer, CERN, Geneva, Switzerland, for providing this information.



6.3.9 South Africa

The radiation-protection regulations in South Africa have been published in the Government Gazette Staatskoerant; Regulation Gazette No. 8454, Vol. 490 in Pretoria 2006. The regulations follow closely the ICRP recommendations. The essential points are:

radiation-exposed workers

The occupational exposure of radiation workers shall be so controlled that the following limits are not exceeded:

* an average effective dose of 20 mSv per year averaged over five consecutive years,
* a maximum effective dose of 50 mSv in any single year,
* an equivalent dose to the lens of the eye of 150 mSv in a year, and
* an equivalent dose to the hands and feet or the skin of 500 mSv in a year;
* in special circumstances a temporarily changed increased dose limit may be approved subject to the agreement of the affected employees, provided that all reasonable efforts are being made to improve the working conditions to the point where compliance with the above dose limits can be achieved.

apprentices and students

For apprentices and students aged between 16 and 18 years the dose limit is 6 mSv in a year and, correspondingly, 50 mSv for the lens of the eye and 150 mSv for the extremities or the skin.

pregnancy

The dose limit for women is generally the same as for men. However, following the declaration of a pregnancy, a dose limit of 2 mSv to the abdomen for the remainder of the pregnancy applies.

emergency situations

In case of emergency situations the following increased dose limits apply: For actions intended to avert a large collective dose or to prevent the development of catastrophic conditions, all reasonable efforts must be made to keep doses to the worker below twice the maximum annual dose limit as given above. For the purpose of saving life or preventing serious injury every effort shall be made to keep the doses below ten times the maximum annual dose limit. Interventions, which may result in their doses approaching or exceeding ten times the annual dose limit, may only be performed when the benefits to others clearly outweigh the risk of the workers undertaking the interventions.

exceptional doses

The annual effective dose limit for members of the public is 1 mSv. This limit also applies for visitors to the sites, where radiation sources are handled or ionizing radiation (e.g. by accelerators) is produced.

general public

In the detailed document mentioned above the exclusion of actions, the exemptions with and without further consideration, the exemption for the transport of radioactive material, the licensing, and the clearance are also defined. In the annex to the regulations the exempt radioactivity concentrations and exempt total radioactivities are given for all radioactive isotopes.

6.4 Supplementary Information

Example 1

exemption limits

clearance levels

unconditional clearance

The various national regulations on radiation protection define limits on the activity of radioactive material that can be handled without restrictions (*exemption limits*), and limits on the specific activity of radioactive waste (*clearance levels*). For the exemption limits values for the maximum allowed specific activity below which no special regulations apply are also defined. For the clearance levels one has to distinguish between the 'normal' clearance levels and the levels for unconditional clearance. Levels for unconditional clearance concern, for example, contaminated scrap or soil. If the activity per gram falls below the unconditioned clearance level, the material is considered no longer to be radioactive.

A dose of 10 μSv per year has been widely considered to be a reasonable basis for the exemption and clearance levels, i.e., an exposure to such material should not lead to an annual dose of more than 10 μSv for an individual.

Consider e.g. the unconditioned clearance level of soil contaminated by ^{137}Cs. According to many national radiation-protection regulations the clearance level for ^{137}Cs is 60 Bq/kg. If one is exposed to such contaminated soil, one will be exposed mainly to the γ rays from the excited decay product, namely ^{137}Ba*. This isotope emits 662-keV γ rays. For an exposure from the soil one would get a dose rate of

$$\dot{H} = \Gamma_\gamma \frac{A}{r^2} \; , \qquad (6.1)$$

where $\Gamma_\gamma = 8.46 \times 10^{-14} \frac{\text{Sv m}^2}{\text{Bq h}}$ (see Table 2.3). For a clearance level of $A = 60\,\text{Bq/kg}$ and a typical distance from the soil of $r = 1$ meter the annual dose can be worked out if a reasonable exposure time and an amount of 'effective' soil is assumed. For an irradiation from 1000 kg of soil over a period of 8 hours a day in 241 days (365 minus weekends and holidays) one arrives at an annual dose of

annual dose

$$H = 10\,\mu\text{Sv} \; . \qquad (6.2)$$

This example just serves to demonstrate the chosen unconditioned clearance level which might lead to an annual dose of 10 μSv for individuals.

unconditioned clearance level

Example 2

Tritium is an isotope of hydrogen. It has a half-life of 12.3 years and decays by β-ray emission. Tritium will equilibrate after intake into the human body and will consequently deliver a dose to the whole body. According to the National Council on Radiation Protection (NCRP) in the United States the Annual Limit on Intake (ALI) is 80 mCi ($\approx$ 3 GBq) corresponding to a Committed Effective Dose Equivalent (CEDE) of about 5 rem (50 mSv) whole-body dose. This corresponds to the maximum permitted dose per year for a worker in a radiation area in the United States. Translated into European safety regulations the associated ALI level would be $\frac{20}{50} \times 3\,\text{GBq} = 1.2\,\text{GBq}$.

ALI level

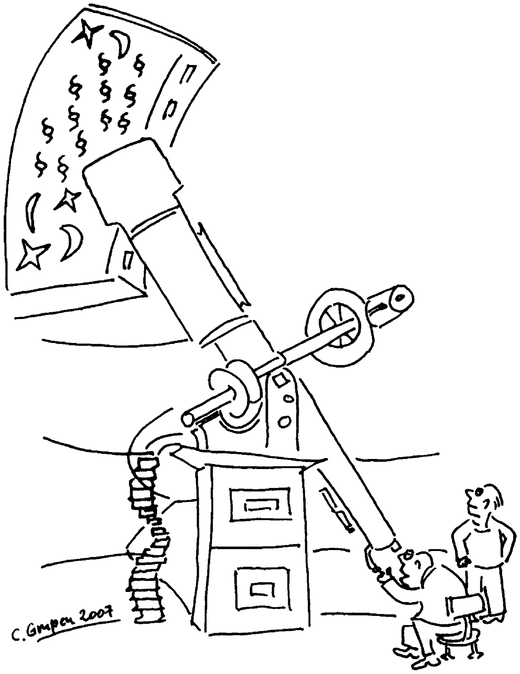
Example 3

The International Commission on Radiological Protection (ICRP) has also calculated the relationship between the activity taken into the body (intake) and the committed effective dose equivalent from intake. The corresponding ALI levels include the type of radiation, its energy, a possible selective deposition in the human body, and the effective half-life, which can be worked out from the physical and biological half-life.

intake

^{131}I is a typical radioisotope which could be inhaled after radiation accidents in nuclear power plants, or which has frequently been used in the past for the diagnosis of functional problems of the thyroid gland. The thyroid gland is also the critical organ for ^{131}I, i.e., it will accumulate predominantly in this gland. The ICRP has worked out that an inhalation of 200 kBq of ^{131}I will lead to a selective deposition in the thyroid gland of 50 mSv. If the tissue weighting factor for the thyroid gland (0.05) is taken into consideration, this gives an effective whole-body dose equivalent of $H_{\text{eff}} = 50\,\text{mSv} \times 0.05 = 2.5\,\text{mSv}$, which would be in accordance with the dose limits of a category-B worker in a radiation-controlled area.

critical organ



"This regulation jungle is even harder to interpret than black holes!" © by Claus Grupen

Summary

Most countries follow the recommendations of the International Commission on Radiological Protection when the safety standards for radiation protection have to be defined and regulated. The details are very complicated, but some general guide marks can be outlined. The dose limits for radiation workers in most cases are at 20 mSv per year. The corresponding limits for the general public is at 1 mSv per year. As a rule the ALARA principle, to keep the doses as low as reasonably achievable, can be considered as a sound guideline for radiation protection. One must always keep in mind that additional doses must be compared to the environmental radiation of about 2 mSv per year present nearly all over the world. It is impossible to present all regulations for every country in this book. A convenient compilation which lists useful radiation-safety references and web sites for the whole world can be found under `www.radiation.org.uk/`. A helpful summary for the European regulations is also found under `http://irpall.irpa.net/pdfs/KL-5a.pdf`.

6.5 Problems

Problem 1

krypton load

With the help of a chemical separation technique the noble gas krypton is to be extracted form the normal air. The krypton concentration for ground-level air is 1.1 ppm. The air activity that can be traced back to the radioactive krypton isotope ^{85}Kr presently amounts to 1.1 Bq/m^3. The radioisotope ^{85}Kr originates mainly from nuclear power plants. This isotope is a typical fission fragment and can easily be released into the environment. How many cubic meters of krypton in the present isotopic abundance in air corresponds to an exemption limit of 1×10^4 Bq?

Problem 2

isotope ratios

A mineral hunter has found a lump of uranium ore of natural isotopic abundance, whose total activity corresponds to 1×10^4 Bq. The isotopic abundance of natural uranium is ^{238}U : ^{235}U : ^{234}U = 99.275% : 0.7195% : 0.0055%, and the half-lives of the isotopes are
$T_{1/2}(^{238}\mathrm{U}) = 4.5 \times 10^9$ yrs,
$T_{1/2}(^{235}\mathrm{U}) = 7 \times 10^8$ yrs,
$T_{1/2}(^{234}\mathrm{U}) = 2.4 \times 10^5$ yrs.
How many kilograms of natural uranium are contained in the lump of uranium ore?

Problem 3

dose limits

A category-A worker in a fuel-reprocessing plant has received a whole-body dose of 12 mSv by external irradiation and a liver dose of 40 mSv by incorporating radioactive material in a controlled area. What kind of maximum extra annual whole-body dose is allowed for the worker, if no other exposures would occur? What would be the maximum allowable lung dose, if, apart from the 12 mSv whole-body dose and the 40 mSv liver dose, no other exposures would occur. Assume for the calculation that the total dose limit is given by the ICRP recommendation.