DESIGN OF ROOMS FOR RADIATION SOURCES

This Guide is valid as of 1 October 2011 until further notice.
It replaces Guide ST 2.2, Radiation safety of radiotherapy equipment and treatment rooms, issued on 2 February 2001 and Guide ST 3.6, Radiation safety in x-ray facilities, issued 24 September 2001.

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Authorization

The Radiation Act stipulates that the party running a radiation practice is responsible for the safety of the operations. The responsible party is obliged to ensure that the level of safety specified in the ST Guides is attained and maintained.

Under section 70, paragraph 2, of the Radiation Act (592/1991), STUK – Radiation and Nuclear Safety Authority (Finland) issues general instructions, known as Radiation Safety Guides (ST Guides), concerning the use of radiation and operations involving radiation.

Translation. In the event of any differences in interpretation of this guide, the Finnish and Swedish versions shall take precedence over this translation.

1 General

This guide specifies the design requirements for radiation shields and radiation safety arrangements for rooms in which radiation sources are used as well as the rooms adjacent to them. The design of these rooms shall also pay special attention to safety arrangements.

This Guide applies primarily to facilities which have radiation appliances emitting photon radiation (gamma rays and X-rays) and in which radioactive substances as sealed sources are used. Appendixes A, B and C in this Guide provide instructions, calculation formulae and parameter tables for the design of radiation shielding for the rooms of the most common photon radiation sources in industry and health care.

This Guide also applies to rooms where appliances and substances are used to produce neutron radiation, particle accelerator facilities in research or in radio nuclide production, and to irradiation facilities. However, no separate instructions or formulae are given for the design of radiation shielding for such rooms and facilities.

This Guide applies to rooms in which unsealed sources are handled only as regards the radiation shielding of such rooms.

ST Guides relating to different applications of radiation use give in detail application-specific instructions and requirements concerning the required warning and safety arrangements.

STUK's authority to confirm the requirements for the design of structures and rooms affecting the safe use of radiation appliances and radioactive substances is laid down in the Radiation Act (592/1991), sections 24 and 26.

2 Dose constraints and planning limits

2.1 Dose constraints

In radiation work, workplaces shall be classified into controlled areas and supervised areas, where appropriate, and areas outside of them are considered unclassified.

Radiation shields for rooms for radiation sources and the adjacent rooms shall be designed and constructed so that the radiation exposure due to the sources remains as low as is reasonably achievable and the effective dose in no case exceeds the following dose constraints:

- 6 mSv per year in a supervised area
- 0.3 mSv per year in an unclassified area.

Dose constraints are source-specific. However, if several radiation sources are in use in one room, they shall be considered as one source in the view of the radiation shielding of this room. If there are several adjacent rooms in which sources are used, the combined effect of all the radiation sources in them shall be considered so that the dose limits stipulated in the Radiation Decree are not exceeded.

The classification of controlled and supervised areas is prescribed in section 32 of the Radiation Act. The classification of areas is dealt with in more detail in Guide ST 1.6. The provisions concerning STUK's authorization to set dose constraints are issued in paragraph 2, section 7 of the Radiation Decree (1512/1991). Dose limits are prescribed in the Radiation Decree, chapter 2. The definitions for effective dose and other dose quantities in this Guide are given in Guides ST 1.9 and ST 7.2.

2.2 Planning limits

The dose constraints in item 2.1 refer to the effective dose. Instead of the effective dose, radiation shielding design uses quantities measurable at a specified place. Radiation shielding design in this Guide is based on the ambient dose equivalent, the value of which is a sufficiently accurate approximation of the effective dose due to external radiation at a point of measurement.

In continuous and regular use, weekly service values are often applied to radiation appliances. Weekly values can also be applied to the ambient dose equivalent. Where this is the case, all shields shall be designed so that the weekly values for the ambient dose equivalent remain as low as is reasonably achievable and in no case exceed the following approximations:

- 120 μSv per week in a supervised area
- 6 μSv per week in an unclassified area.

3 Design and construction of radiation shielding

3.1 Orientation factors and occupancy factors

Radiation shielding design can use orientation and occupancy factors in order to take into account the use of the radiation source and the uses of the rooms adjacent to the source room.

The value of the orientation factor U in the specified direction shall always be greater to or equal to that proportion of the appliance's operating time which the appliance's primary radiation is oriented in this direction during its expected use. If a radioactive substance is used unshielded, the orientation factor shall be given the value $U = 1$ in all directions.

The effective dose per year to a person in a particular room can be estimated by multiplying the ambient dose equivalent per year determinend for this room by the occupancy factor T estimated for the room. The occupancy factor shall be given the following values:

- Work areas in continuous use, $T = 1$.
- Patient rooms and waiting rooms in health care, $T = 1$. If people do not occupy the waiting room continuously during the use of radiation, a smaller occupancy factor value may be applied to this room. However, the value shall not be any less than $T = 0.1$.
- Living quarters and lounges not under the control of the responsible party, $T = 1$.
- Indoor and outdoor premises where no individuals remain on a continual basis (such as toilets, corridors, dressing rooms, storerooms and parking places), T shall have a value greater than or equal to the proportion of time which the individual who occupies the place the longest may stay there. However, the value shall not be any less than $T = 0.1$, unless there are specific, justified grounds for such a value.

3.2 Planning distances

When assessing the attenuating effects of radiation shields, the following values shall be applied to the distances from the shields of persons who work in supervised or unclassified areas or when they occupy these areas:

- behind or above the shield, 0.3 m
- beneath the shield, 1.5 m measured from the floor of the room below the shield.

The justification for these values is that no person will occupy space closer than 0.3 m to the wall, and no person's body will be, on the average, more than 1.5 m above the floor. Greater values may be used if it can be shown that the distances for occupancy are systematically greater than the given values. However, it shall be noted that the combined effects of several radiation sources or scattered radiation may cause the dose rate to be the highest in places other than those at the given distances from the shields (see Verification of the adequacy of shielding in item 3.4).

3.3 Radiation appliance and its use

The acceleration voltage of a radiation appliance (or the X-ray tube voltage), the field size of primary radiation, and the dose rate of radiation may vary during use. When designing radiation shields for appliance rooms, the voltage, field size and dose rate values can be those that accord with the expected use of the appliance. However, the values must not be underestimated. Neither is it acceptable to underestimate the appliance's orientation factors or workloads, nor the occupancy factors of the adjacent rooms. If the way the appliance is used or the intended use of the adjacent rooms changes, or if a new appliance is introduced into the room, the adequacy of all radiation shields shall be reassessed according to the changed circumstances.

The attenuating effects of the object exposed to radiation (the patient, an object in imaging or irradiation) and its support (such as the treatment table or the examination stand) are usually not noted. However, when designing radiation shielding for primary radiation for an appliance room, it may be reasonable to note a shield integrated into the structure of the appliance and covering the whole primary beam.

If radiation is used in several shifts, all radiation shields must be designed with a view to the shift which causes the highest exposures to radiation. The combined use of radiation in all shifts shall be considered when the shielding concerns

- living quarters

- indoor rooms not under the control of the responsible party
- patient rooms.

3.4 Other aspects

Placement of rooms and sources

The shield thicknesses required for rooms where radiation sources are used may be decreased by locating the rooms in areas with no other activity nearby. For example, the shielding requirements for gamma radiation from positron emitters and isotope ^{131}I in nuclear medicine are decreased if the patients' waiting rooms and isolation rooms are located apart from other rooms in constant use. Current rooms that are already shielded can also be made use of.

Shield thicknesses can also be reduced by the proper placing of radiation sources (for example, by directing the primary radiation from the source appropriately).

Construction and coverage of shields

The radiation shield in the direction of primary radiation shall cover no less than the area possibly exposed to primary radiation.

Attention shall be paid to the homogeneity of radiation shielding and to the appropriateness of the shielding material. Intermediate floor structures in buildings are often constructed of profiled concrete slabs or cavity slabs. In such cases, the thickness of the concrete in all places is not as great as the nominal thickness of the shield. The radiation shielding in such constructions must be improved to make it adequate at each point. The same procedure shall apply to, for example, walls of hollow brick.

Lead sheets used in shielding constructions shall be tightly connected with butt or lap joints. When butt joints are used, additional lead strips should be placed over the joints to take account of possible gaps between the sheets.

Holes and thin parts in any shields, such as pipes inside the wall construction, electrical sockets and switches etc., must all be taken into account. In addition, attention must be paid to the appropriate shielding capacity of the doors, door frames, windows and window frames of the rooms. The shielding capacity of shields must be uniformly adequate. If frequent measurements requiring electrical and instrument cabling are conducted in a shielded room, then holes or ducts for the cables shall be planned with a view to radiation safety and appropriately integrated into the shields of the room.

In all X-ray activities in health care, the lead equivalents of all shields must be clearly marked on any doors equipped with radiation shields. In addition, all lead glass windows must have their lead equivalents clearly marked.

Verification of the adequacy of shielding

The responsible party shall verify that all shields are constructed as planned in every detail and that they are adequate.

Appropriate supervision during the construction phase is essential for ensuring the adequacy of shielding. After the shields are in place, their adequacy can be ascertained through radiation measurements.

Radiation measurements shall be conducted at least at those distances from the shields which were used as working and occupancy distances when designing the shields (see item 3.2). On occasion, it may be expedient to conduct measurements elsewhere as well; this is the case when, for example, the shielded place is exposed to radiation scattered from facility structures and passing by the shields, or when the place is exposed to radiation from many sources. If the shielding capacity of the ceiling or roof structure is slight, it is necessary to consider scatter radiation from the air space above the structure (skyshine). Measurements shall be conducted in sufficiently many locations to ensure the coverage and uniformity of all shields. Special attention should be paid to any joints connecting shields of different materials, and to door and window frames, because their shielding capacity has exhibited the most deficiencies due to faulty construction techniques.

If any area is found adjacent to the room of radiotherapy equipment in which the radiation dose rate exceeds 20 µSv/h, care shall be taken that no person is required to work there or occupy such an area for longer times.

4 Radiation safety arrangements

4.1 Warning signs and warning lights

General requirements
Doors near radiation sources or leading to rooms in which sources are used shall carry signs calling attention to a radiation hazard when it is necessary to warn of a hazard caused by ionizing radiation.

A sign forbidding permanent occupancy shall be used to indicate any room for which the shields have been calculated using an occupancy factor T < 1 and which nobody is expected to occupy continuously (e.g. storage rooms and cleaning closets).

If warning lights are used in the immediate vicinity of doors leading to a room in which radiation sources are used, the recommended operation for the lights is the following:

- A yellow or white light indicating that the radiation appliance is ready for operation. It is recommended that this light bears the text “APPLIANCE OPERATIONAL”.
- A red light indicating that the radiation appliance is producing radiation, or that the radioactive substance is unshielded. It is recommended that this light bears the text “NO ENTRY”.

The lights should be placed at a natural height for viewing, or they must be easily noticeable otherwise.

The source container of any radioactive substance shall be equipped with a sign warning of a radiation hazard and a sign indicating both the activity of the source(s) at any given time and the radionuclide involved.

Warning signs for radiation sources are discussed in Guide ST 1.3, and signs in rooms of use in Guide ST 1.6.

Special requirements for radiotherapy
Any door leading to the treatment room shall bear a sign indicating that the room is used for radiotherapy.

Inside the treatment room, a red signal light (or an acoustic signal) shall indicate radiation output from the radiotherapy equipment. For an afterloading unit, this light shall be connected to a continuous-action dose rate monitor. This allows the signal light to function self-sufficiently and to be independent of the control system of the therapy equipment.

If the afterloading unit incorporates, in addition to the source container, other continuously radiating components with a surface dose rate exceeding 20 µSv/h, a sign warning of radiation must be attached to these components, too.

During radionuclide therapy and some brachytherapies, the patients are often isolated for a few days, usually in their own rooms. The door to such a room is not required to bear any warning signs or signal lights in addition to the above mentioned sign warning of a radiation hazard and a sign indicating that the room is used for radiotherapy.

Special requirements for industry
The special requirements concerning shielded enclosures used for industrial radiography are given in Guide 5.6. The special requirements concerning sealed sources and the use of control and analytical X-ray apparatuses are given in Guides ST 5.1 and ST 5.2.

Special requirement for unsealed sources
The special requirements for the use of unsealed sources are given in Guides ST 6.1, ST 6.2 and ST 6.3.

4.2 Other radiation safety arrangements

General requirements
Unauthorized access to rooms in which radiation sources are used and which are classified as controlled areas shall be prevented by structures, safety interlocks or access control.

At least one of the doors to the room in which radiation sources are used must be capable of being opened from within the room at all times. Entrance to and exit from the room must also be possible when the door’s automatic opening system is out of order.

In medical uses of radiation, the patient must be seen and heard from the control room, and it must also be possible to talk to the patient in the treatment room or examination room. In addition, the control room must have an unobstructed view to the doors to the relevant treatment and examination rooms, unless these doors are locked.

Sizes of rooms in which radiation sources are used

The floor surface area and geometry of any room in which radiation sources are used are designed according to the type of activity. There shall be enough working space around any sources so that radiation safety is ensured, and when necessary, it must be possible to use mobile shields and ceiling-mounted shields.

Special requirements for radiotherapy

At the entrance to the treatment room, there must be two safety devices which, independently of each other, prevent the operation of the therapy equipment if someone tries to enter the treatment room. One of these safety devices shall be a switch preventing the operation of the therapy equipment if the door is not closed. The switch must be of a type that prevents the operation of the equipment even in the case of damage to the switch. It is recommended that the other safety device be a door-mounted photocell device that interrupts the operation of the equipment when someone passes the cell. Both devices shall be connected in such a way that the operation of the equipment can only be continued from the control console.

The monitoring device in an accelerator treatment room is recommended to be e.g.a camera with which it can be ensured that no individuals other than the patient remain in the room during treatment.

The treatment room and the control room shall be equipped with clearly visible emergency stop buttons which, if pressed, interrupt the operation of the equipment, stop its motion, and disconnect the acceleration voltage or cause the radioactive substances to return to their container. The continuation of the treatment shall be possible only from the control console. Afterloading equipment shall, in addition, have a device which allows returning the radioactive substances manually to their container.

The source container in afterloading equipment shall be constructed in such a way that it is not possible to remove radioactive substances from the container without special tools. If, in the case of a breakdown, any radioactive substances should get outside the source container, the staff must have the means at hand for temporarily shielding the substances.

For the isolation of a patient receiving brachytherapy or radionuclide therapy (see item 4.1, Special requirements for radiotherapy), no special equipment or arrangements to ensure the radiation safety are required in addition to the radiation shielding, if any, of the isolation room. The personnel shall, however, be given instructions concerning the use of the isolation room (such as instructions regarding visitors and workers in the room).

Special requirements for industry

The special requirements concerning shielded enclosures used for industrial radiography are given in Guide 5.6.

Special requirements for unsealed sources

The special requirements for the use of unsealed sources are given in Guides ST 6.1, ST 6.2 and ST 6.3.

5 Approval of radiation shielding and rooms

When processing the safety licence application and also in connection with the relevant site inspections, STUK inspects the radiation shielding and radiation safety arrangements for all rooms in which radiation is used as well as for all rooms adjacent to them. STUK approves the shielding for the rooms of the most common radiation sources provided that they comply with the requirements of this Guide, and also the relevant safety arrangements, provided that they comply with the requirements of this Guide as well as the application-specific requirements in other ST Guides. The shielding and arrangements for any other uses of radiation are approved on the basis of the requirements in this Guide together with case-specific safety assessments.

When radiation shielding is being planned, STUK will, upon request, provide an advance statement concerning the adequacy of the shields. An advance statement should be requested when the following facilities are being designed:

- A-type laboratories[*)]
- radiotherapy rooms
- accelerator facilities[*)]
- irradiation facilities or any rooms for irradiation appliances
- shielded enclosures for industrial imaging in which the intention is to use particle accelerators or high-activity sealed sources.

The advance statement should be requested early in the planning stage, preferably prior to the approval of the construction plan.

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*) When A-type laboratories are designed, in addition to an advance statement concerning the shielding, plans concerning the discharges of the laboratories shall be delivered to STUK for statement as described in Guide ST 6.1. A statement is also required for the design of an accelerator facility meant for radionuclide production.

Appendix A

Design of radiation shielding in the most common cases

Radiation shielding design for rooms in which radiation sources are used can utilize specific software, Monte Carlo algorithms, or measurement-based data. The Monte Carlo method may be particularly useful in situations in which the effects of multiple scattering require attention.

If calculation software or other methods are not available, shields can be designed using the methods, calculation formulae and parameters presented in this Appendix together with those in Appendixes B and C. It should be noted that the formulae and the respective parameter values will yield results that will not in any case lead to an underestimation of the shielding required. Due to uncertainty of calculation, the final assurance of the adequacy of shielding will only be obtained by measurements.

A.1 Radiotherapy accelerators

The workloads of accelerators in radiotherapy are expressed in terms of absorbed dose to water. Its unit is the gray (Gy). Most often, shielding calculations on photon radiation can, with sufficient accuracy, consider the value of the absorbed dose expressed in units of Gy as the value of the ambient dose equivalent expressed in units of Sv.

Primary radiation

Transmission factor B for radiation shields required for primary radiation for rooms in which radiotherapy accelerators are used is calculated using Formula (B4) in Appendix B so that the weekly workload W of the equipment (absorbed dose to water in the isocentre in a week) is substituted for the product $\dot{H}_0 \cdot t$. In Formula (B4), d_0 is then the distance of the appliance's target from the isocentre.

The value for the weekly workload W of the equipment shall be at least 800 Gy/week (800 Sv/week). A smaller value is acceptable if it can be shown that the workload is less than this on a permanent basis.

The tenth value layers for accelerators' primary radiation for several shielding materials and acceleration voltages are given in Table C1 in Appendix C.

Leakage radiation

Transmission factor B_v for radiation shields required for leakage radiation for rooms in which radiotherapy accelerators are used is calculated using Formula (B5) in Appendix B so that $\dot{H}_v$ is given a value which is 0.5% of the isocentre dose rate. A smaller value is acceptable if it can be shown that the dose rate of leakage radiation is less than this. The value of leakage radiation is expressed at a distance of one metre from the target of the accelerator, therefore in Formula (B5) d_0 = 1 m.

The TVL_e values given in Table C1 in Appendix C can be used for tenth value layers for leakage radiation from accelerators for given shielding materials.

Scattered photon radiation

Transmission factor B_s for radiation shields required for photon radiation scattered from the patient or the walls, floor or ceiling of the room, for rooms in which radiotherapy accelerators are used, is calculated using Formula (B6) in Appendix B so that the weekly workload W is substituted for the product $\dot{H}_0 \cdot t$. In addition, A in the formula is given the value of the area on the surface of the scattering object exposed to primary radiation. In Formula (B6), d_0 is then the distance of the appliance's target from the isocentre.

If the ceiling or roof structure in the accelerator room is thin, and the accelerator is directed upward, it is necessary to consider separately the radiation scattered from the air space above the structure (skyshine) to the adjacent rooms.

The values for primary radiation scattering factors for several scattering angles and acceleration voltages are given in Table C2 in Appendix C. The tenth value layers for scattered photon radiation for lead and concrete for several acceleration voltages and scattering angles are given in Tables C3-1 and C3-2 in Appendix C.

Compared to photon leakage radiation, the proportion of scattered photon radiation is, most often, insignificant at acceleration voltages of over 10 MV.

Neutron radiation

If a radiotherapy accelerator operates at an acceleration voltage of over 10 MV, the appliance will inevitably produce neutron radiation. The best shielding for neutrons is provided by substances containing hydrogen. Radiotherapy accelerator shields are most often constructed of concrete which contains hydrogen as it contains also water. If concrete shields are designed adequate for photon radiation, they are, in general, adequate for neutron radiation, as well. In such a case, the only place in which neutron radiation needs to be specifically considered is the door in the passageway to the radiotherapy treatment room, as neutrons produced in the treatment room can scatter there along the passageway. If needed, the passageway must be equipped with a shielding door.

The dose rate of the neutron radiation produced in an accelerator and scattered to the door of the treatment room along the passageway can be estimated using Formula (B7) in Appendix B.

A.2 Use of X-ray appliances in health care

Radiation output from X-ray appliances in health care is expressed in terms of air kerma. Its unit is the gray (Gy). Most often, shielding calculations concerning X-rays can, with sufficient accuracy, consider the value of the air kerma expressed in units of Gy as the value of the ambient dose equivalent expressed in units of Sv.

The radiation shields in rooms where X-ray appliances are used should be designed so that the adjacent areas need not be classified as supervised. This requirement is usually easily reached, allowing the unrestricted use of any surrounding areas.

In the use of X-rays, control rooms not shielded up to the ceiling or without doors should be avoided. Such open rooms may lead to restrictions for the staff as they carry out their duties during, for example, pregnancy.

Conventional X-ray appliances

In conventional uses of X-ray appliances in health care, radiation shields do not need to be calculated theoretically for most X-ray rooms[*)]. Most often, a shield of 3 mm of lead or 300 mm of concrete suffices in the direction of primary radiation. In directions affected only by leakage radiation and scattered radiation, shields of 2 mm of lead or 200 mm of concrete are enough. Such a shield generally extends to a height of no less than 2 m. Higher than this, 1 mm of lead or 100 mm of concrete usually suffices, provided that a greater thickness is not required for the protection of any upper floor facilities.

Mammography appliances

To shield mammography appliances, 0.25 mm of lead suffices (corresponding to 1.3 mm of steel, 30 mm of concrete or 78 mm of plasterboard), provided the imaging voltage is less than 35 kV. If mammography appliances are located in a room with concrete or brick walls, additional shielding is usually not required for the walls. However, the need for additional shielding for a window (to watch the patient) and doors must be separately estimated.

If the user of the appliance is in the examination room during the examination and cannot use fixed shields, his/her radiation protection, where necessary, shall be arranged through, for example, user shields mounted on the appliance, or mobile shields.

Conventional dental imaging appliances, shielded appliances and appliances with small-size beams and low power

Rooms with conventional dental imaging appliances, well-shielded X-ray appliances, or low-power appliances operating on small-size beams (such as shielded X-ray appliances for imaging tissue samples or bone mineral density measurement appliances with small-size beams)

*) Conventional use of X-ray appliances in health care here refers to activities involving the most common X-rays of bone, soft tissue and respiratory organs (the voltage of equipment not more than 150 kV) with the number of examinations per year not more than 10 000.

do not necessarily require specific radiation shielding. However, the need for shielding shall be assessed if the walls of the appliance room are of lightweight construction (e.g. wood, plasterboard or chipboard).

If the user of the appliance is in the examination room during the examination, his/her radiation protection, where necessary, shall be arranged through, for example, mobile shields.

Some examples of the specification of shielding for dental imaging appliances are given in STUK's publication "Hammasröntgentoiminnan laadunvalvonta ja kuvaushuoneen säteilysuojaus" (STUK opastaa 1/2011) ("Quality control of dental X-ray practices and radiation shielding of imaging room" (Advice from STUK 1/2011)).

Fixed fluoroscopy appliances and computed tomography appliances

The shields for rooms in which fixed fluoroscopy appliances or computed tomography equipment (CT equipment) are used shall be specifically calculated where the rooms are small in surface area and the appliance is placed close to a wall or control room. In addition, if the workload of the appliance is exceptionally great, shields shall be specifically calculated. In other cases, shields with lead equivalents of 3 mm suffice.

Transportable X-ray appliances and fluoroscopy appliances

If fixed shields cannot be introduced when using transportable X-ray appliances, the radiation protection of the user of the appliance, any other workers and the patients shall be arranged through personal protective devices and mobile shields. If any appliance is used continuously in one room (e.g. in an operating room), the shielding requirement of such a room shall be specifically investigated.

Other appliances

Shields for rooms for health care X-ray appliances, if these rooms were not mentioned above, or if their shielding requirements were specifically referred to above, are designed as presented in the following items.

Primary radiation

Transmission factor B for a radiation shield required for primary radiation for a room in which an X-ray appliance is used in health care is calculated using Formula (B4) in Appendix B so that the product $W{\cdot}K$ is substituted for the product $\dot{H}_0 \cdot t$. Here W is the weekly workload (mAmin/week) and K is the radiation output of the X-ray tube.

The radiation output K of an X-ray tube in units of mGy/mAmin (mSv/mAmin) at a distance of one metre from the focal spot of the tube at several tube voltages is presented in Table C4 in Appendix C. In Formula (B4), then d_0 = 1 m.

The tenth value layers for X-ray appliances´ primary radiation for several shielding materials and tube voltages are given in Tables C5-1, C5-2 and C5-3 in Appendix C. The lead equivalents of certain shielding materials are given in Table C6 in Appendix C.

Leakage radiation

Transmission factor B_v for radiation shields required for leakage radiation for rooms in which X-ray appliances are used in health care is calculated using Formula (B5) in Appendix B, inserting $\dot{H}_v$ = 1 mSv/h (0.25 mSv/h in the case of conventional dental imaging appliances). A smaller value is acceptable if it can be shown that the dose rate of leakage radiation is less than this. The dose rate of leakage radiation is determined at a distance of one metre from the focal spot of the tube; therefore d_0 = 1 m in Formula (B5). The leakage radiation value $\dot{H}_v$ = 1 mSv/h refers to the maximum voltage permitted for the appliance and the permitted maximum tube power averaged in one hour. Therefore, the effective time in one week shall be used in Formula (B5) (the time in one week corresponding to the greatest continuous tube current), in other words $t = W/I_{jatk}$, in which I_{jatk} equals the greatest tube current permitted for continuous use in one hour, and W equals the weekly workload of the appliance.

The TVL_e values given in Tables C5-1, C5-2 and C5-3 in Appendix C can be used for tenth value layers for leakage radiation from X-ray appliances for given shielding materials and tube voltages.

Scattered radiation
Transmission factor B_s for radiation shields required for radiation scattered from the patient, for rooms in which X-ray appliances are used in health care, is calculated using Formula (B6) in Appendix B so that the product $W \cdot K$ is substituted for the product $\dot{H}_0 \cdot t$. If the values in Table C4 are inserted for K, then d_0 = 1 m in Formula (B6). In addition, A in the formula is given the value of the area on the surface of the scattering object exposed to the primary beam.

The values for the scattering factors for primary X-rays for several scattering angles and X-ray tube voltages are given in Table C7 in Appendix C. The TVL values for primary radiation given in Tables C5-1, C5-2 and C5-3 in Appendix C can be used for tenth value layers for scattered X-rays for given shielding materials and tube voltages.

A.3 Use of X-ray appliances in industry, research and education

Separate radiation shields are not required for rooms in which enclosed or shielded X-ray appliances are used. In all other cases, shields are designed as presented in this item.

Enclosed and shielded appliances are discussed in Guide ST 5.2.

Primary radiation
Transmission factor B for radiation shields required for primary radiation for rooms in which X-ray appliances are in industrial use is calculated using Formula (B4) in Appendix B. Here, the dose rate of the primary radiation of the appliance must be known.

The tenth value layers for industrial X-ray appliances' primary radiation for several shielding materials and tube voltages are given in Tables C5-1, C5-2 and C5-3 in Appendix C. The lead equivalents of certain shielding materials are given in Table C6 in Appendix C.

Leakage radiation
Transmission factor B_v for radiation shields required for leakage radiation for rooms in which X-ray appliances are in industrial use is calculated using Formula (B5) in Appendix B. Leakage radiation dose rate values $\dot{H}_v$ to be used for industrial radiography appliances shall be the following:

$\dot{H}_v$ = 1 mSv/h, when the tube voltage is lower than 150 kV

$\dot{H}_v$ = 2.5 mSv/h, when the tube voltage is 150–200 kV

$\dot{H}_v$ = 5 mSv/h, when the tube voltage is higher than 200 kV.

Lower values are acceptable if it can be shown that the dose rate of leakage radiation is less than the given values. The dose rate of leakage radiation is determined at a distance of one metre from the focal spot of the tube; therefore d_0 = 1 m in Formula (B5).

The TVL_e values given in Tables C5-1, C5-2 and C5-3 in Appendix C can be used for tenth value layers for leakage radiation from X-ray appliances for given shielding materials and tube voltages.

Leakage radiation of radiography appliances is discussed in Guide ST 5.6.

Scattered radiation
Transmission factor B_s for radiation shields required for radiation scattered from the irradiated object or the walls, floor or ceiling of the room, for rooms in which X-ray appliances are in industrial use, is calculated using Formula (B6) in Appendix B. The dose rate of the primary radiation of the appliance must be known. In addition, A in the formula is given the value of the area on the surface of the scattering object exposed to the primary beam.

The values for the scattering factors for primary X-rays scattered from water are given for several scattering angles and tube voltages in Table C7 in Appendix C. In industrial use of X-rays, the scattering factors for water can be used as safe upper limits for scattering from other materials (concrete, steel), as well. The TVL values for primary radiation given in Tables C5-1, C5-2 and C5-3 in Appendix C can be used for tenth value layers for scattered X-rays for given shielding materials and tube voltages.

A.4 Radioactive substances

Separate radiation shields are not required for rooms in which industrial radiometric measuring appliances containing radioactive substances are used. In all other cases, shields are designed as presented in this item.

Radiometric appliances are discussed in Guide ST 5.1.

Primary radiation

Transmission factor B for radiation shields required for primary radiation for rooms in which appliances containing radioactive substances or in which unshielded radioactive substances (i.e. the substance has no shield of its own) are used, is calculated using Formula (B4) in Appendix B. There, d_0 is the distance of the radioactive substance from the point at which the dose rate of the radiation emitted by the substance is determined, and d is the shortest distance of the radioactive substance to people working in or otherwise occupying the supervised or unclassified area in question. The value $U = 1$ shall be used for orientation factor U if the substance is unshielded.

The tenth value layers for several shielding materials for some commonly-used radioactive substances are given in Table C8 in Appendix C.

If the dose rate $\dot{H}_0$ of the radioactive substance is not known, it can be calculated on the basis of the activity A of the substance as follows:

$$\dot{H}_0 = \Gamma \cdot A \qquad \text{(A1)}$$

In Formula (A1), Γ is the dose rate constant (gamma factor). The values of this constant for some commonly-used radioactive substances are presented in Table C9 in Appendix C. These values express the dose rates from radionuclides with activities of 1 GBq at a distance of one metre from the substance. If the dose rate thus calculated is inserted into Formula (B4) in Appendix B, then $d_0 = 1$ m.

Leakage radiation

Transmission factor B_v for radiation shields required for leakage radiation for rooms in which appliances containing radioactive substances are in use is calculated using Formula (B6) in Appendix B. There, d_0 is the distance of the radioactive substance from the point at which the dose rate of the leakage radiation emitted by the substance is determined, and d is the shortest distance of the radioactive substance to people working in or otherwise occupying the supervised or unclassified area. In addition, $t = 1$ shall be inserted for work spaces and living quarters and for facilities that may be continuously occupied.

The following values shall be used for $\dot{H}_v$ for leakage radiation from the source container of a radioactive substance at a distance of one metre from the surface of the container:

$\dot{H}_v$ = 7.5 µSv/h for industrial radiometric measuring appliances

$\dot{H}_v$ = 10 µSv/h for afterloading equipment in radiotherapy

$\dot{H}_v$ = 20 µSv/h for industrial radiography appliances.

When these values are used in Formula (B5) of Appendix B, then $d_0 = 1$ m. Smaller dose rate values are acceptable if it can be shown that the dose rate is less than the given values.

The TVL_e values given in Table C8 in Appendix C can be used for tenth value layers for given shielding materials for leakage radiation from appliances containing radioactive substances.

The dose rates of leakage radiation from source containers are discussed in Guides ST 5.1 and ST 5.6.

Scattered radiation

Transmission factor B_s for radiation shields required for radiation scattered from the irradiated object, for rooms in which appliances containing radioactive substances are used, is calculated using Formula (B6) in Appendix B. There, d_0 is the distance of the radioactive substance from the point at which the dose rate of the radiation emitted by the substance is determined, and d_1 is the distance of the radioactive substance from the scattering object.

Values for scattering factors for radiation emitted from radioactive substances are provided for concrete and steel as well as for certain scattering angles in Table C10 in Appendix C. The tenth value layers for primary radiation from each particular radioactive substance (Table C8 in Appendix C) can be used as tenth value layers for scattered radiation for given shielding materials. However, when the scattering angle is greater than 70°, the tenth value layers for positron emitters can be used for ^{60}Co, ^{137}Cs,

^{226}Ra and other nuclides with gamma energies of over 0.5 MeV. The tenth value layers for primary radiation shall be used for them as well with scattering angles of less than 70°.

Appendix B

Calculation formulae

In this appendix, a “(radiation) dose” always refers to the ambient dose equivalent, unless otherwise specified.

Transmission factor and thickness of shield

When designing radiation shields, the first item to calculate is a transmission factor B, which refers to the ratio of the dose H through the shield to the dose H_0 in the case of no shield:

$$B = H / H_0 \,. \tag{B1}$$

The number n of tenth value layers TVL required for a shield is calculated from the transmission factor as follows:

$$n = log_{10}(1/B) \,. \tag{B2}$$

Then, the shield thickness s equals

$$s = n \cdot TVL_1, \quad \text{if } n \leq 1 \tag{B3-1}$$

$$s = TVL_1 + (n-1) \cdot TVL_2, \quad \text{if } 1 < n \leq 2 \tag{B3-2}$$

$$s = TVL_1 + TVL_2 + (n-2) \cdot TVL_3, \quad \text{if } 2 < n \leq 3 \tag{B3-3}$$

$$s = TVL_1 + TVL_2 + TVL_3 + (n-3) \cdot TVL_e, \quad \text{if n} > 3 \tag{B3-4}$$

where TVL_1, TVL_2 and TVL_3 are the first, second and third tenth value layers
TVL_e is the equilibrium tenth value layer (the tenth value layer behind a strongly attenuating shield).

In radiation protection, the values to be used for tenth value layers and half-value layers (1 HVL_e = 0.3 TVL_e) shall be the values measured in a wide-beam geometry.

When the required thicknesses have been calculated for leakage radiation and scattered radiation, the shielding thickness required for the combined effect of these components can be determined from the difference of the calculated thicknesses in the following way:

- If the difference between the thicknesses is less than one TVL_e, the necessary shielding thickness will be the larger thickness added with one more HVL_e.
- If the difference between the thicknesses is equal to or larger than one TVL_e, the larger of the thicknesses can be used as the necessary thickness.

If the TVL_e values of leakage radiation and scattered radiation differ from each other, the safest way is to use the larger of these for calculations. Some computing software used in shielding design may note the combined effects of radiation components without any actions on the user’s part.

Primary radiation

Transmission factor B for a shield required for primary radiation in a room in which radiation appliances*) are used is calculated using the formula

$$B = \frac{\dot{H}_A \cdot d^2}{\dot{H}_0 \cdot t \cdot U \cdot T \cdot d_0^{\,2}} \tag{B4}$$

where

- $\dot{H}_A$ is the planning value (either 120 µSv/week (6 mSv/year) or 6 µSv/week (0.3 mSv/year) depending on whether the shield is intended for the protection of individuals working in or otherwise occupying a supervised area or an unclassified area)
- $\dot{H}_0$ is the dose rate of the appliance's primary radiation at a distance of d_0 from the target (focal spot) of the appliance
- t is the proportion of the time which the appliance produces radiation of the weekly working hours**)
- U is the orientation factor of the appliance in the respective direction
- T is the occupancy factor
- d_0 is the distance of the appliance's target (focal spot) from the point at which the dose rate of the primary radiation is determined
- d is the distance of the appliance's target (focal spot) from any individuals working in or otherwise occupying a supervised area or an unclassified area.

Leakage radiation

Transmission factor B_v for a shield required for leakage radiation in a room in which radiation appliances are used is calculated using the formula

$$B_v = \frac{\dot{H}_A \cdot d^2}{\dot{H}_v \cdot t \cdot T \cdot d_0^{\,2}} \tag{B5}$$

where

- $\dot{H}_A$ is the planning value (either 120 µSv/week (6 mSv/year) or 6 µSv/week (0,3 mSv/year) depending on whether the shield is intended for the protection of individuals working in or otherwise occupying a supervised area or an unclassified area)
- $\dot{H}_v$ is the dose rate of the appliance's leakage radiation at a distance of d_0 from the target (focal spot) of the appliance
- t is the proportion of the time which the appliance produces radiation of the weekly working hours**)
- T is the occupancy factor
- d_0 is the distance of the appliance's target (focal spot) from the point at which the dose rate of the leakage radiation is determined
- d is the distance of the appliance's target (focal spot) from any individuals working in or otherwise occupying a supervised area or an unclassified area.

Scattered radiation

Transmission factor B_s for a shield required for scattered radiation in a room in which radiation appliances are used is calculated using the formula

$$B_s = \frac{\dot{H}_A \cdot d_1^{\,2} \cdot d_2^{\,2}}{\dot{H}_0 \cdot t \cdot \alpha \cdot A \cdot T \cdot d_0^{\,2}} \tag{B6}$$

*) In this case, "radiation appliance" can refer to an unshielded radioactive substance, as well.

**) See item 3.3. chapter 3 concerning shift work.

where

$\dot{H}_A$ is the planning value (either 120 µSv/week (6 mSv/year) or 6 µSv/week (0.3 mSv/year) depending on whether the shield is intended for the protection of individuals working in or otherwise occupying a supervised area or an unclassified area)

$\dot{H}_0$ is the dose rate of the appliance's primary radiation at a distance of d_0 from the target (focal spot) of the appliance

t is the proportion of the time which the appliance produces radiation of the weekly working hours***)

α is the scattering factor in the relevant direction

A is the area on the surface of the scattering object exposed to the primary beam

T is the occupancy factor

d_0 is the distance of the appliance's target (focal spot) from the point at which the dose rate of the primary radiation is determined

d_1 is the distance of the appliance's target (focal spot) from the scattering object

d_2 is the distance of the scattering object from any individuals working in or otherwise occupying a supervised area or an unclassified area.

Scattering of neutrons from radiotherapy accelerators

The dose rate $\dot{H}_s$ of scattered neutron radiation at door opening (with no door) to the passageway to the therapy room can be calculated using the formula:

$$\dot{H}_s = \dot{H}_0 \cdot \frac{A_0}{A_1} \cdot \frac{d_0^2}{d_1^2} \cdot 10^{-d_2/5\mathrm{m}} \tag{B7}$$

where

$\dot{H}_0$ is the dose rate of neutron radiation at a distance of d_0 from the appliance's target

A_0 is the cross-sectional area of the opening from the passageway to the treatment room

A_1 is the cross-sectional area of the passageway

d_0 is the distance of the appliance's target from the point at which the dose rate of neutron radiation is determined

d_1 is the distance of the appliance's isocentre from the point on the centre line of the passageway which still allows a view to the isocentre

d_2 is the distance of the door opening of the passageway from the point on the centre line of the passageway which still allows a view to the isocentre.

Formula (B7) can be used for calculating the neutron dose rate for the cases where there is one bend between the treatment room and the passageway. If there are two bends, the added distance due to the second bend shall be noted in parameter d_2, and, in addition, the coefficient 1/3 shall be added to the right side of the formula.

Neutrons scattering from the treatment room along the passageway to the door opening produce high-energy photon radiation (gamma radiation) due to their scattering and absorption reactions in the passage walls. The dose rate of this radiation at the door opening is 25–50% of the neutron dose rate.

The following tenth value layers can be used for designing the shield required for the passageway door:

- neutron radiation, *TVL* = 45 mm paraffin or hydrogenous plastic material
- photon radiation, *TVL* = 61 mm lead.

The hydrogenous material on the door construction shall be on the side of the treatment room and the passageway.

***) See item 3.3. chapter 3 concerning shift work.

Appendix C

Parameter values for calculation formulae

The tenth value layers and lead equivalents given for the shielding materials in this appendix are valid for the following material densities:

- lead 11.3 g/cm^3
- steel 7.4–7.9 g/cm^3
- concrete 2.3–2.4 g/cm^3
- solid brick 1.8 g/cm^3
- plaster 0.84 g/cm^3.

Table C1. Tenth value layers for primary radiation (MV range) [7].

Acceleration voltage (MV)	Tenth value layer (mm) for various shielding materials (TVL_2=TVL_3=TVL_e)					
	Lead		Steel		Concrete	
	TVL_1	TVL_e	TVL_1	TVL_e	TVL_1	TVL_e
2	35	40	75	70	220	200
4	50	55	90	90	290	290
6	55	55	100	100	350	350
8	55	55	105	105	380	380
10	55	55	105	105	410	400
12	55	55	105	105	440	420
15	55	55	110	110	470	440
20	55	55	110	110	490	450
25	55	55	110	110	510	460

Table C2. Scattering factors for primary radiation (MV range) [6].

Acceleration voltage(MV)	Scattering factor (m²/cm²) for various scattering angles					
	30°	45°	60°	90°	135°	150°
6	$6.9 \cdot 10^{-6}$	$3.5 \cdot 10^{-6}$	$2.1 \cdot 10^{-6}$	$1.1 \cdot 10^{-6}$	$0.75 \cdot 10^{-6}$	$0.72 \cdot 10^{-6}$
10	$8.0 \cdot 10^{-6}$	$3.4 \cdot 10^{-6}$	$1.9 \cdot 10^{-6}$	$1.0 \cdot 10^{-6}$	$0.76 \cdot 10^{-6}$	$0.69 \cdot 10^{-6}$

The scattering factor is given for scattering from the patient (water). It expresses the ratio of the dose of scattered radiation, measured at a distance of one metre from the patient, to the dose in the primary beam, measured on the patient's skin (no back-scatter) when the field size on the patient's skin equals 1 cm^2.

The scattering angle of 0° means that the direction of scattered radiation is the same as the direction of primary radiation. Respectively, the scattering angle of 180° means that the direction of scattered radiation is the opposite to the direction of primary radiation.

Table C3-1. Tenth value layers for lead for scattered radiation (MV range) [6].

Accelera-tion volt-age (MV)	Tenth value layer (mm) for various scattering angles ($TVL_2=TVL_3=TVL_e$)									
	30°		45°		60°		90°		120°	
	TVL_1	TVL_e	TVL_1	TVL_e	TVL_1	TVL_e	TVL_1	TVL_e	TVL_1	TVL_e
4	33	37	24	31	18	25	9	13	5	8
6	38	44	28	34	19	26	10	15	5	8
10	43	45	31	36	21	27	12	16	8	14

The tenth value layer is given for radiation scattered from the patient (water). Scattering angle of 0° means that the direction of scattered radiation is the same as the direction of primary radiation. Respectively, scattering angle of 180° means that the direction of scattered radiation is the opposite to the direction of primary radiation.

Table C3-2. Tenth value layers for concrete for scattered radiation (MV range) [6].

Accelera-tion volt-age (MV)	Tenth value layer (mm) for various scattering angles ($TVL_1=TVL_2=TVL_3=TVL_e$)					
	15°	30°	45°	60°	90°	135°
4	300	250	220	210	170	140
6	340	260	230	210	170	150
10	390	280	250	220	180	150

The tenth value layer is given for radiation scattered from the patient (water). Scattering angle of 0° means that the direction of scattered radiation is the same as the direction of primary radiation. Respectively, scattering angle of 180° means that the direction of scattered radiation is the opposite to the direction of primary radiation.

Table C4. Radiation output of an X-ray tube [8].

X-ray tube voltage (kV)	Radiation output (mGy/mAmin)
30	2.6
50	1.1
70	2.2
85	3.3
100	4.7
125	7.2
150	9.8

Radiation output values are determined at a distance of one metre from the focal spot of the tube. The total filtration of the tube equals approximately 2.5 mm of aluminium at all kV values except at 30 kV where molybdenum filtering is used.

Table C5-1. Tenth value layers for primary radiation (kV range) for lead, 50–150 kV [8], 200–400 kV [2]. The values for 30 kV and 35 kV were calculated in STUK on the basis of the information in reference [5].

X-ray tube voltage (kV)	Tenth value layer (mm) for lead			
	TVL_1	TVL_2	TVL_3	TVL_e
30	0.015	0.025	0.036	0.05
35	0.018	0.032	0.049	0.07
50	0.07	0.13	0.18	0.25
70	0.13	0.28	0.37	0.42
85	0.19	0.47	0.62	0.67
100	0.25	0.66	0.84	0.93
125	0.35	0.69	0.87	1.0
150	0.45	0.66	0.87	1.3
200	0.6	0.8	1.1	1.4
250	0.9	1.5	2.0	3.6
300	2.0	2.7	4.3	5.4
400	3.6	5.0	6.4	8.2

Table C5-2. Tenth value layers for primary radiation (kV range) for steel, 50–150 kV [8]. The values for 30 kV and 35 kV were calculated in STUK on the basis of the information in reference [5].

X-ray tube voltage (kV)	Tenth value layer (mm) for steel			
	TVL_1	TVL_2	TVL_3	TVL_e
30	0.07	0.12	0.20	0.28
35	0.08	0.16	0.28	0.36
50	0.4	0.8	1.1	1.3
70	0.9	1.7	2.6	3.1
85	1.3	3.1	4.5	5.0
100	1.8	4.4	6.1	
125	2.8	7.1		
150	4.2	10.6		

Table C5-3. Tenth value layers for primary radiation (kV range) for concrete, 50–150 kV [8], 200–400 kV [2]. The values for 30 kV and 35 kV were calculated in STUK on the basis of the information in reference [5].

X-ray tube voltage (kV)	Tenth value layer (mm) for concrete			
	TVL_1	TVL_2	TVL_3	TVL_e
30	1,6	2,9	4,3	6,4
35	1,8	3,7	6,1	8,1
50	11	18	21	25
70	19	30	37	39
85	23	43	48	48
100	31	50	53	53
125	42	60	62	63
150	50	68	70	72
200	65	83	83	83
250	71	87	87	87
300	75	100	100	100
400	135	100	95	95

Table C6. Lead equivalents of certain shielding materials (kV range) [7]. The values equivalent to 0.5 mm of lead were calculated in STUK.

Shielding material	Thick-ness of lead (mm)	Thickness (mm) of shielding material equivalent to the thickness of lead at various X-ray tube voltages (kV)					
		50	70	100	150	200	300
Concrete	0.5	65	58	51	56		
	1	130	105	80	105	95	80
	2		195	140	180	165	125
	3		285	190	250	220	155
	4			240	300	270	185
	6			340	410	360	240
Brick (solid)	0.5	94	84	74	81		
	1	200		120	150	130	105
	2			195	260	230	165
	3			260	340	310	210
	4			330	420	370	250
	6			450	570	490	330
Steel	0.5	3.0	3.2	3,4	5.1		
	1	6.5		6,5	14	16	16
	2			13	28	32	26
Plaster	0.5	157	145	132	153		
	1	290		200	270	240	190

Table C7. Scattering factors for primary radiation (kV range), 30–150 kV [5], 200–300 kV [3].

X-ray tube voltage (kV)	Scattering factor (m^2/cm^2) for various scattering angles					
	30°	45°	60°	90°	120°	135°
30	$0.6\cdot10^{-6}$	$0.2\cdot10^{-6}$	$0.2\cdot10^{-6}$	$0.3\cdot10^{-6}$	$0.9\cdot10^{-6}$	$1.3\cdot10^{-6}$
50	$4.7\cdot10^{-6}$	$4.1\cdot10^{-6}$	$3.7\cdot10^{-6}$	$3.9\cdot10^{-6}$	$5.1\cdot10^{-6}$	$5.9\cdot10^{-6}$
70	$5.1\cdot10^{-6}$	$4.4\cdot10^{-6}$	$4.1\cdot10^{-6}$	$4.3\cdot10^{-6}$	$5.4\cdot10^{-6}$	$6.2\cdot10^{-6}$
100	$5.5\cdot10^{-6}$	$4.9\cdot10^{-6}$	$4.5\cdot10^{-6}$	$4.7\cdot10^{-6}$	$5.9\cdot10^{-6}$	$6.7\cdot10^{-6}$
125	$5.9\cdot10^{-6}$	$5.3\cdot10^{-6}$	$4.9\cdot10^{-6}$	$5.1\cdot10^{-6}$	$6.3\cdot10^{-6}$	$7.1\cdot10^{-6}$
150	$6.3\cdot10^{-6}$	$5.7\cdot10^{-6}$	$5.3\cdot10^{-6}$	$5.5\cdot10^{-6}$	$6.7\cdot10^{-6}$	$7.5\cdot10^{-6}$
200	$6.0\cdot10^{-6}$	$5.0\cdot10^{-6}$	$4.8\cdot10^{-6}$	$4.8\cdot10^{-6}$	$6.8\cdot10^{-6}$	$7.0\cdot10^{-6}$
250	$6.3\cdot10^{-6}$	$5.3\cdot10^{-6}$	$4.8\cdot10^{-6}$	$4.8\cdot10^{-6}$	$6.8\cdot10^{-6}$	$7.0\cdot10^{-6}$
300	$6.5\cdot10^{-6}$	$5.5\cdot10^{-6}$	$5.0\cdot10^{-6}$	$4.8\cdot10^{-6}$	$6.5\cdot10^{-6}$	$7.0\cdot10^{-6}$

The scattering factor is given for scattering from the patient (water). It expresses the ratio of the dose of scattered radiation, measured at a distance of one metre from the patient, to the dose in the primary beam, measured on the patient's skin (no back-scatter) when the field size on the patient's skin equals 1 cm^2.

The scattering angle of 0° means that the direction of scattered radiation is the same as the direction of primary radiation. Respectively, the scattering angle of 180° means that the direction of scattered radiation is the opposite to the direction of primary radiation.

Table C8. Tenth value layers for radiation emitted from radioactive substances, ^{60}Co, ^{137}Cs, ^{192}Ir, ^{226}Ra [2], positron emitters, ^{99}Mo, ^{99m}Tc, ^{111}In, ^{123}I, ^{131}I, ^{201}Tl [9].

Radioactive substance	Tenth value layer (mm) for various shielding materials ($TVL_3=TVL_e$)								
	Lead			Steel			Concrete		
	TVL_1	TVL_2	TVL_e	TVL_1	TVL_2	TVL_e	TVL_1	TVL_2	TVL_e
Positron emitters*)	15	15	14	63	44	43	225	150	125
^{60}Co	45	40	40	72	70	70	280	205	205
^{99}Mo	20	25	24	56	58	45	210	160	155
^{99m}Tc	0,9	0,9	0,9	20	17	16	145	90	75
^{111}In	2,5	3,5	3,5	31	29	29	160	105	95
^{123}I	2	10	17	21	31	45	130	110	115
^{131}I	11	17	22	56	43	44	210	140	140
^{137}Cs	21	22	22	65	50	50	210	165	165
^{192}Ir	12	18	18	48	42	42	170	140	140
^{201}Tl	1,3	1,3	1,3	12	21	21	105	90	90
^{226}Ra	44	44	44	80	70	70	250	245	245

*) For example ^{11}C, ^{13}N, ^{15}O, ^{18}F.

Table C9. Dose rate constants of certain radioactive substances [1], ^{226}Ra [10].

Radioactive substance	Dose rate constant (mSv/h)/GBq
Positron emitters*)	0.16
^{60}Co	0.33
^{99}Mo	0.046
^{99m}Tc	0.022
^{111}In	0.072
^{123}I	0.034
^{131}I	0.064
^{137}Cs	0.092
^{192}Ir	0.14
^{201}Tl	0.018
^{226}Ra	0.20

*) For example ^{11}C, ^{13}N, ^{15}O, ^{18}F.

The dose rate constant refers to the dose rate of a radioactive substance with an activity of 1 GBq, in air at a distance of one metre from the substance.

Note! The dose calculated on the basis of the dose rate constant for short-lived substances (half-life in the range of some minutes) is (noticeably) greater than the actual dose from this substance in one hour.

Table C10. Scattering factors for radiation emitted from radioactive substances [4].

Radiation energy (MeV)	Scattering factor (m^2/cm^2) for various scattering angles					
	105°		120°		180°	
	Concrete	Steel	Concrete	Steel	Concrete	Steel
0.2	$2 \cdot 10^{-6}$	$0.7 \cdot 10^{-6}$	$3 \cdot 10^{-6}$	$1 \cdot 10^{-6}$	$5 \cdot 10^{-6}$	$2 \cdot 10^{-6}$
0.5	$1 \cdot 10^{-6}$	$0.7 \cdot 10^{-6}$	$2 \cdot 10^{-6}$	$1 \cdot 10^{-6}$	$2 \cdot 10^{-6}$	$2 \cdot 10^{-6}$
1.0	$0.6 \cdot 10^{-6}$	$0.5 \cdot 10^{-6}$	$1 \cdot 10^{-6}$	$0.7 \cdot 10^{-6}$	$1 \cdot 10^{-6}$	$0.9 \cdot 10^{-6}$
2.0	$0.4 \cdot 10^{-6}$	$0.3 \cdot 10^{-6}$	$0.6 \cdot 10^{-6}$	$0.4 \cdot 10^{-6}$	$0.6 \cdot 10^{-6}$	$0.5 \cdot 10^{-6}$

The scattering factor expresses the ratio of the dose of scattered radiation, measured at a distance of one metre from the scattering material, to the dose in the primary beam, measured on the surface of the scattering material (no back-scatter) when the field size on the surface of the scattering object equals 1 cm^2.

The scattering angle of 0° means that the direction of scattered radiation is the same as the direction of primary radiation. Respectively, the scattering angle of 180° means that the direction of scattered radiation is the opposite to the direction of primary radiation.

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Appendix D

Definitions and concepts

Tenth value layer (*TVL*)
The material layer which reduces the radiation dose or radiation dose rate to one-tenth of its initial value.

Occupancy factor (*T*)
The factor which indicates the proportion of the time that any individuals work in or otherwise occupy a room which receives radiation while a radiation source produces output.

Primary radiation
Radiation from the source not attenuated by the shield of the source itself.

Half-value layer (*HVL*)
The material layer which reduces the radiation dose or radiation dose rate to one-half of its initial value.

Scattered radiation
Radiation which has deviated from its initial direction or lost some of its initial energy when encountering an object.

Additional explanation: This Guide regards radiation scattered within the shield of the source itself as leakage radiation.

Orientation factor (*U*)*)
The factor which indicates the proportion of the time that primary radiation is directed in a certain direction while a radiation source produces output.

Radiation appliance
An appliance which produces radiation electrically or contains any radioactive substance.

Radiation source
A radiation appliance or radioactive substance.

(Radiation) shielding
Reduction of the dose rate of radiation through the use of radiation shields.

(Radiation) shield
Material, structure or device used for reducing the dose rate of radiation.

Additional explanation: In this Guide, the term "radiation shield" does not refer to the shield of the radiation appliance itself, i.e. a shield or shell immediately adjacent to the radiating part of the appliance, nor does the term refer to the source container or a similar device in any afterloading equipment.

Radiation safety measures
Procedures to prevent and decrease radiation doses and detrimental effects of radiation to humans and to ensure the safety of the responsible party's own workers, students and apprentices as well as the safety of the members of the public and any outside workers working for the responsible party. These procedures also include the measures which aim to prevent accidents and mitigate their results.

Security arrangements
Measures to detect and prevent the theft, sabotage or unlawful transfer of a radiation source, unlawful entry to an institution or facilities which contain these sources, or a similar malicious act. These measures also include the counter-measures after a malicious act.

Leakage radiation
Radiation from the source through the radiation shield of the source itself.

*) In some texts this factor is also called for "Use factor".