Protection against Ionizing Radiation.

1. Czech legislation and IOCB regulations.

Law, which regulates all applications of ionizing radiation, is the **Atomic Act 263/2016 Sb**. The Atomic Act gives definitions of principle terms and declares rules for the relations between subjects. For all acts concerning the license to work with the sources of ionizing radiation, the control of correct practice and verification of personnel qualification is authorised the State Office for Nuclear Safety (in Czech: Státní úřad pro jadernou bezpečnost – SÚJB).

Bylaw No. 422/2016 Sb. gives details about radiation protection when working with radioisotopes.

Both documents are based on **Directive 2013/59/Euratom**.

The broad area of peaceful application of ionizing radiation is covered starting with energy production in nuclear power plants, going through nuclear medicine up to the radiation techniques in research and development. The following text will cover only the topics concerned with work with the open radiation sources in the limits common for life sciences labs.

Operation manual for work with radioisotopes in the laboratories of I. category on IOCB CAS is an internal regulation specifying the operation protocols for handling compounds labelled by radionuclides on IOCB CAS.

2. Principal terms.

The bellow presented principal terms and their definitions are partly taken from the English version of Directive 2013/59/Euratom ([a]) or from Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, IAEA, Vienna, 2014 ([b]). Where the definition of the term used in the Czech laws has not direct correspondence in international legislation, the Czech term was translated by author of this text ([c]).

ionizing radiation [a] (IR) - the transfer of energy in the form of particles or electromagnetic waves of a wavelength of 100 nanometre or less (a frequency of 3×10^{15} Hertz or more) capable of producing ions directly or indirectly

γ **(**gamma**) radiation** – stream of photons with energies from 10 keV to several thousands of keV

β □□□□□□□□□ [c] – stream of negatively charged electrons with energies from 10 keV to several thousands of keV

α **radiation** [c] – stream of positively charged nuclei of helium with energies of the order of MeV

radiation generator [a] **–** means a device capable of generating ionising radiation (e.g. X-ray machine, accelerator of charged particles)

radiation source [a] – means an entity that may cause exposure, such as by emitting ionising radiation or by releasing radioactive material

radioactive material [a] – means material incorporating radioactive substances

radioactive source [a] – means a radiation source incorporating radioactive material for the purpose of utilising its radioactivity

activity [a] – the activity, **A**, of an amount of a radionuclide in a particular energy state at a given time is the quotient of dN by dt, where dN is the expectation value of the number of spontaneous nuclear transitions from that energy state in the time interval dt:

$$A = \frac{dN}{dt}$$

The SI unit of activity (one disintegration per second) is **Bq** (bequerel). Another frequently used unit, especially for higher activities, is **1 Ci (**curie) = $3.7.10^{10}$ Bq = 37 GBq

radioactive substance [a] **-** Any substance that contains one or more radionuclides the activity or concentration of which cannot be disregarded from a radiation protection view.

sealed source [a] **–** means a radioactive source in which the radioactive material is permanently sealed in a capsule or incorporated in a solid form with the objective of preventing, under normal conditions of use, any dispersion of radioactive substances; must be accompanied by the certificate in which it is stated under which conditions the tightness is guaranteed

unsealed source [b] **–** a source that does not meet the definition of a sealed source.

radiation protection (against) [b] **–** the protection of people from harmful effects of exposure to ionising radiation and the means for achieving this goal

exposed worker [c] – a person, either self-employed or employee, who is subject to exposure at work and who is liable to receive doses exceeding the dose limits for public exposure

exposed worker, category "A" [c] **–** those exposed workers who are liable to receive an effective dose greater than 6 mSv per year.

exposed worker, category "B" [c] – those exposed workers who are liable to receive an effective dose higher then is the limit for public exposure but under 6 mSv per year

workplace [c] **–** a part of laboratory characterized by its protecting properties (isolation, ventilation, blinding) where the radioisotopes are handled (e.g. radiochemical hood, hermetical glove box, bench, etc.); in one laboratory there can be several workplaces if every workplace is independent unit from the point of view of the organization of work.

contamination [b] – the presence of radioactive substances in or on a material or the human body or other place where they are unintended or undesirable or could be harmful.

radioactive waste [b] – material, whatever its physical form, remaining from practices or interventions and for which no further use is foreseen that contains or is contaminated with radioactive substances and has an activity or activity concentration higher than the level for clearance from regulatory requirements

radioactive waste management facility [b,c] – facility specifically designated to handle, treat, condition, temporarily store or permanently dispose of radioactive waste; the treatment could be licensed introduction of the radioactive waste to the environment followed by its dispersion

radioactive discharges [c] – radioactive substances arising from a source within a practice which are discharged as gases, aerosols, liquids or solids to the environment, generally with the purpose of dilution and dispersion

exposure [a, b] – a condition of being exposed to ionising radiation;
1. controlled or planned exposure
2. emergency exposure situation as a result of an accident, a malicious act or other unexpected event

external exposure [b] – exposure to radiation from sources outside the body.

internal exposure [b] – exposure to radiation from a source within the body.

radiological emergency of I. degree [c] – an accident the consequence of which is or could be unacceptable exposure of exposed workers and intolerable discharge of radioactive substances to the laboratory space; there is no threat to the staff outside the radioisotope laboratory and to the general public; the laboratory staff is able and have resources needed to manage the situation themselves. The declaration of radiological emergency of I. degree must be reported to SUJB without delay

conversion inhalation factor ($\mathbf{h_{inh}}$) [c] – coefficient equal to the **effective dose** resulting from the intake of **1 Bq** of a given radionuclide (in the form of vapours) by person; it is used for planning of radiation protection measures or for accident evaluation; this coefficient summarizes all corrections on the type and energy of radiation of given radioisotope, on its biological half-life and on the sensibility of different tissues of the human body.

3. Interaction of ionizing radiation with matter

On passing through the matter the ionising radiation creates pairs of positively charged atoms or molecules and negatively charged electrons – the energy of photons or particles is thus gradually consumed as excitation energy. Total energy absorbed in unit of matter is called dose (**D**) of ionising radiation. Basic unit of dose is **1 Gy** (grey) = 1 J/kg. **Dose rate** than represents increase of dose in time during exposure and is very important quantity for radiation protection calculations.

Qualities of ionising radiation during interaction with matter are characterised by linear transfer of energy **L**:

$$L = \frac{dE}{dx}$$

L is expressed in units as J/m, keV/m or eV/μm. High value of **L** means that the transfer of energy from particles or photons takes place on short path. The typical **L** values for different types of ionising radiation and for solid matter are listed bellow:

RTG photons with energy 200 keV	L = 1,7 eV/μm
$\boldsymbol{\beta^-}$ particles with 100 eV	L = 20 eV/μm
α particles with energy 5 MeV	L = 40 eV/μm

Biological effects of particles with the same energy but characterised with different **L** are different. The reason is that damage caused by particles with high **L** is concentrated to small volume of tissue whether the low **L** means that the damage is dispersed in the greater volume of tissue. Living organism has greater chance to cope with the damage caused by ionising radiation if the concentration of damage is lower. To be able to characterise biological effects of dose of ionising radiation we must introduce equivalent dose **H = Q.D** . **Q** is quality coefficient that is turning function of **L** and generally the higher the **L** the higher the **Q**.

The basic unit of **H** is **1 Sv** (sievert). The values of **Q** for different types of ionising radiation are given bellow:

γ (photonic radiation)	1	
β (electrons)	1	
neutrons	5 - 20	(according the energy)
protons	5	
α particles, heavy nuclei	20	

Neutrons are neutral particles and thus they do not ionise the matter directly. On the other hand they are readily absorbed by the atomic nuclei and such a nuclear reaction yields unstable radioactive nuclei and high energetic electrons, protons and α–particles i.e. ionising radiation. Therefore the flux of neutrons is regarded from the point of view of radiation protection as an ionizing radiation.

4. Biological effects of ionizing radiation

The consequence of direct ionisation and cleavage of biomolecules is loss of their biochemical function. Due to lower concentration of biomolecules these processes are relatively less important than radiolysis of water. Water makes in average 70% of weight of biological material. Radiolysis of water is complicated process of reactions after the primary ionisation. Regarding the biological effects of ionising radiation the most important process is creation of $OH^{\cdot}$ radicals:

$$H_2O \longrightarrow H^{\bullet} + OH^{\bullet}$$

This creates the oxidation milieu ($OH^{\cdot}$ radicals are the principal species in the so called Fenton reagent used to mild oxidation of sugars) and the biomolecules are damaged by the oxidation reactions with the resulting loss of their biochemical role.

On the cell level the most important damages are changes of cytogenetical information – damage of DNA. The majority of these changes are lethal – the cells division capability is lost and as a consequence the capability of regeneration of living tissues is diminished. That is why the rapidly growing tissues and tissues and organs with a short half-life of renewing (mucosal tissues, glands, bone marrow) are more vulnerable to radiation damage than other (muscles, bones). If the extent of cell damage is low the cell conserves its viability and the result is mutated cell. To characterise the different sensibility of biological tissues to radiation damage the equivalent dose in tissue or organ $\mathbf{H_T}$ is defined as $\mathbf{H_T = w_T.H}$. Effective dose **E** in sieverts, that is crucial for the evaluation of the radiation burden of human organism is then calculated according to the following equation:

$$E = \sum_T w_T . H_T$$

Tissue radiation weight factors $\mathbf{w_T}$ are shown in Table 1. The lower the value of $\mathbf{w_T}$ for the tissue the lower is the sensibility of the tissue to the radiation damage. The sum of $\mathbf{w_T}$ for the whole body is 1.

Table 1. Tissue radiation weight factors for man

Tissue or organ	w_T	$\sum w_T$
Bone marrow (red), colon, lung, stomach, breast, remainder tissues	0.12	0.72
Gonads	0.08	0.08
Bladder, oesophagus, liver, thyroid,	0.04	0.16
Bone surface, brain, salivary glands, skin	0.01	0.04
TOTAL		**1.0**

The biological effects are divided to two categories – **deterministic effects** and **stochastic effects**.

The **deterministic** effects are observed only when effective dose **E** exceeds certain threshold level. For man the threshold level **E = 1 Sv** (Fig. 1, graph A). Over the threshold level the severity of the effects is directly proportional to the effective dose. The first symptom is radiation erythema (the same as you can observe after sun burn). The higher doses provoke acute radiation syndrome (radiation sickness). The symptoms are nausea, diarrhoea and damage of central nervous system (confusion, hampered orientation in space). The lethal dose for man is 10 Sv and death comes in several weeks.

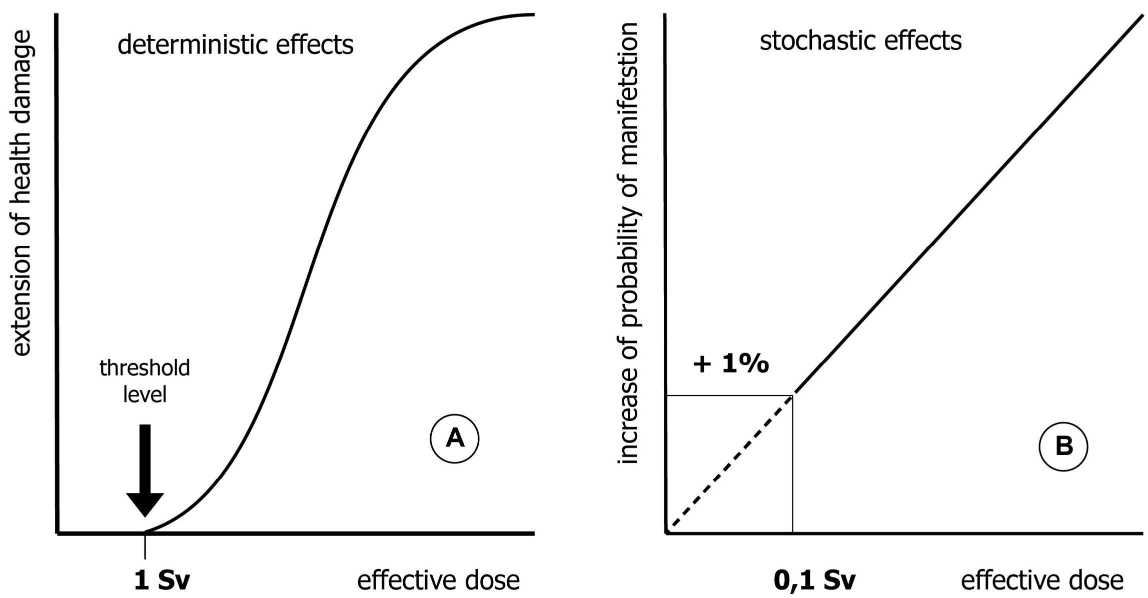

Fig. 1. Deterministic and stochastic effects as a funtion of effective dose.

The **stochastic** effects are due to nonlethal changes of cytogenetic material of cells. These effects are delayed 10 or more years from the time of exposure. The probability of manifestation of disease symptoms is proportional to the obtained dose. On the other hand the severity of symptoms is not related with the effective dose as it is for deterministic effects. The syndrome of drying and deteriorating skin on hands of radiologists in the first half of the last century is one of such ailments. More important are tumours and cancer diseases. In clinical terms it is not possible to discern tumours and cancers caused by ionising radiation from those caused by other agents e.g. chemical substances. However, the increased probability of cancers in population that obtained higher than 0.1 Sv doses of ionising radiation in comparison with general population exposed only to doses resulting from natural background is well documented. The graph B in Fig. 1 illustrates this relation. For the low doses the increase of probability of cancer manifestation is very low. To dose 0.1 Sv (that is the five times as much yearly dose limit for exposed workers) corresponds cancer manifestation probability increase 1 %. The part of line in graph B represented by broken line is not proofed unequivocally yet. The straight line continuation of the graph for the doses lower than 0.1 Sv is unconditionally accepted only from the radiation safety point of view. According to one of the scientific hypotheses the manifestation of stochastic effects is observed only when the effective dose exceeds the threshold level – 0.1 Sv.

5. Delimitation of Supervised Areas and Controlled Areas

Delimitation of areas where the sources of ionizing radiation are used is the basic organizational measure of protection against radiation.

Supervised Area (**Sledované pásmo** in Czech) is delimitated in the laboratories in which during the standard operation and during the previsible deviations from standard operation conditions the exposure of workers would exceed the limit for general population (1 mSv/year). Access of the Supervised Area is not restricted but only the exposed workers B who passed the training in the work with radioisotopes are authorized to work there. The entrance doors of laboratories where the Supervised Area is delimited have following warning sign:

Controlled Area (**Kontrolované pásmo** in Czech) is delimited in laboratories where

- average dose rate on working place during the calendar year could exceed 2.5 μSv/h
- the product of volume activities and conversion inhalation factors is on yearly average higher than 2.5 $\mu Sv/m^3$
- surface contamination of workplaces can be higher than 400 $Bq/100cm^2$

Exposed workers A and B have free accesses Controlled Area. However, only exposed workers A are authorized to work with radioactive materials in Controlled Area. Access of other persons as maintenance technicians and visitors is allowed only if accompanied by the exposed worker A and must registered in the Book of Visitors of the Controlled Area. The entrance doors of laboratories where the Controlled Area is delimited have following warning sign:

On IOCB the Controlled Area is delimited only in synthetic laboratories of Laboratory of Radioisotopes.

6. Properties of the most frequently used radioisotopes.

From the point of view of the radiation protection the important characteristics of radioisotopes are half-life, type and energy of emitted ionizing radiation and its range[*] in the air and water. In the Table 1. there are given these characteristics for the radioisotopes most frequently used in life sciences.

Table 2. Most frequently used radioisotopes.

Radioisotope	Type of desintegration	Half-life	E_{max} [MeV]	Range	
				air	water (~skin)
^{3}H	beta	12.7 years	0.019	0.6 cm	0.006 mm
^{14}C	beta	5730 years	0.156	25 cm	0.3 mm
^{35}S	beta	87 days	0.167	26 cm	0.3 mm
^{33}P	beta	25 days	0.249	50 cm	0.6 mm
^{32}P	beta	14 days	1.709	7.9 m	0.8 cm
^{125}I	gamma	60 days	0.027-0.032	50 cm	0.6 mm
^{51}Cr	gamma	27.7 days	0.005-0.323	blinding with 3.2 mm of lead	
^{56}Fe	gamma	2.7 years	0.0059		

[*] In passing through matter the β particle is loosing gradually all its initial energy, the greatest fraction of the energy is lost at the end of the trajectory. The **range** is the trajectory of the β particle with the E_{max}. The energy of gamma radiation diminishes exponentially with the distance. The capacity of material to absorb energy of gamma radiation of given energy is expressed as half-thickness, i.e. the thickness of material which absorbs the half of the incident energy.

7. Detectors of ionizing radiation

Man as other mammals cannot perceive the ionizing radiation directly by its senses. Therefore we must place our confidence in devices that are able to detect it. The detection of the ionization of matter is the physical principle used in all detectors. The capacity of ionizing radiation to cause blackening of photographic plates was observed as first. The discovery of this effect was followed by the discovery of ionization of matter which followed from the capacity of this radiation to discharge electrometers. This principle – gradual discharge of the electrometer – is used for precise calibration assays and in some personal dosimeters until these days.

Geiger-Müller (G–M) tube is the most frequently used detector of ionizing radiation (Fig. 2). There is pressure of gases around 0.1 bar in the tube and the voltage on the electrodes is in the order of hundreds of volts. If detection of soft β radiation is required the entrance window is made from a very thin mica (1.5 mg/cm^2; the window is most often protected by the grid or mesh to avoid contact with solid objects or fingers – the rupture of the window results in ultimate and unreparable damage of the detector tube). Ions created by the passage of ionizing particle or photon are accelerated in the electric field between electrodes and the result is ionization avalanche. An electric current pulse is measurable as voltage pulse on resistor in circuit. Voltage pulse is not proportional to the energy of particles and in the region of electrode voltage called Geiger working voltage the pulse is of the same height for particles with different energy. The composition of gas mixture helps to limit the time of the current pulse after the particle passage – the detector is thus prepared to detect another particle. Notwithstanding, the current pulse lasts up to 100 microseconds and therefore the 1 000 pulses per second is the maximum rate measurable by G–M detector. Display of the detector on the Fig. 2 shows the rate in the most frequent units – counts per minute (cpm) – it is 161 counts per second (cps).

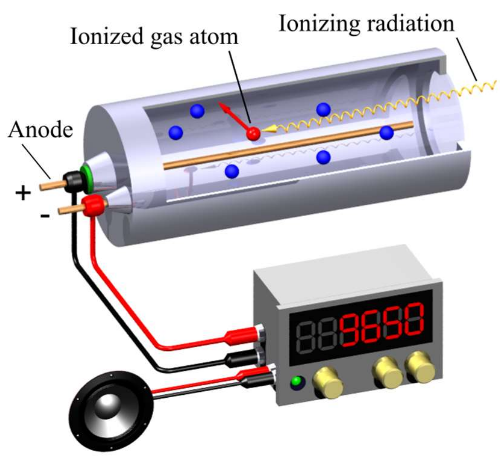

Fig. 2. Detector of ionizing radiation with Geiger-Müller tube.

The G–M tubes with large entrance window around 100 cm^2 are expensive and vulnerable from the mechanical point of view. That is why the currently used large window monitors are based mainly on plastic scintillators. The cascade of energy transfers from primary created ions on scintillator gives raise to pulse of light that is focused on photomultiplier. Intensity of the pulse of light is proportional to the energy of ionizing particle and light pulse and his detection by photomultiplier takes only nanoseconds. Therefore the scintillation detector is able to detect up to 1 million of cpm. The plastic scintillator itself is robust but the photomultiplier tubes generally are fragile to vibrations.

Fig. 3. Contamination monitor with large area scintillation detector.

The above-mentioned contamination detectors can be used for all radionuclides with the exception of radionuclide ^{3}H. The β radiation of tritium has so low energy that it is stopped even with the thinnest entrance window or foil (entrance window of the scintillation detector must be covered by the light tight foil to eliminate day light interference). In the past the tritium contamination monitors based on open proportional detectors continually washed by counting gas (mixture of argon and methane 9:1) were used. Weakness of this type of detectors is not only high consumption of expensive counting gas but also the fact that due to high positive potential on anode very often the dust particles contaminated by tritium were sucked into the detector and it had to be decontaminated. Very often more time was spent by detector decontamination than by monitoring of laboratory and therefore the use of open proportional detectors for tritium contamination monitoring was abandoned. Only method for checking surface tritium contamination is taking the swipes by wetted cotton wool swab, putting this swabs in scintillation vials together with scintillation cocktail and counting the samples on liquid scintillation spectrometer (LSC spectrometer). The intimate mixing of scintillation cocktail with the sample makes possible measurement of the weak β radiation of tritium. The assay of one sample takes about 10 minutes and that is why LSC spectrometers have automatic sampler conveyors with capacity of several hundreds of scintillation vials. As for solid scintillators the intensity of light pulse in scintillation liquids is proportional to the energy of ionizing radiation. This proportionality enables to identify unknown radionuclide by its LSC energetic spectrum if necessary.

8. Protection against ionizing radiation

The target is to make the effective dose obtained by the worker **A**s **L**ow **A**s **R**easonable **A**chievable – ALARA principle.
Effective dose limit for exposed workers is 20 mSv in calendar year.
Equivalent dose H for forearms and for feet should not exceed 500 mSv in calendar year.

Derived yearly limits for intake of most frequently used radionuclides that result in a committed dose 20 mSv from internal exposure are following:

^{3}H	470 Mbq (12.7 mCi)	^{32}P	8,3 Mbq (0.23 mCi)
^{14}C	34 Mbq (0.9 mCi)	^{33}P	83 Mbq (2.24 mCi)
^{35}S	26 Mbq (0.7 mCi)	^{125}I	1.33 Mbq (0.04 mCi)

Protection against **external** exposure.

- **protection by increased distance –** dose rate declines with the square of the distance from the source of ionizing radiation. It can be achieved by using utensils to increase the distance between the source and our body. Radionuclide sources should be stored aside from the most frequented places in the lab.

- **protection by shielding** – it follows from the range values of β-particles (see Table 1) that β radiation of tritium, carbon ^{14}C, sulphur ^{35}S and phosphorus ^{33}P is completely stopped by epidermis[*] – keratinized outermost layer of skin – which is about one hundred times less sensible to radiation damage than other organs of body. The high-energy radiation of phosphorus ^{32}P penetrates up to 8 mm under the skin surface where it could damage the living part of skin – dermis – and organs situated just under the skin. During the work with ^{32}P-labelled compounds we must protect our head and upper body by the Plexiglas shield of 10 mm thickness placed on bench between the source and our body. Particles α are stopped even by the s□□□□□□□□□□□□□□ of higher density. To shield from γ rays the materials with high specific mass as lead or depleted uranium are the most effective.
- **limiting the time of exposition to indispensable minimum** – good planning of work and meticulous preparations make possible shortening of the time of work and consequently the lowering of the dose.

Protection against **internal** exposure

- during the work with the open sources of ionizing radiation it is forbidden to eat, drink or smoke
- the obligatory personal protecting devices used in laboratory of I. category are
  – lab coat
  – gloves (rubber, PVC, PE)
  – protective goggles when working with vacuum devices
- at one workplace only such amount of radioactive material can be handled that corresponds with its protecting qualities
- monitoring of the laboratory
- regulation of the access to laboratory and necessity of authorization for handling radioactive materials

9. Laboratory for the work with unsealed soft β–emitters.

As stated above, β radiation on the contrary to gamma radiation can be completely stopped by clear-cut not very thick sheet of material and consequently the threat of external exposure is very low. Therefore the protection of workers is concentrated on protection against internal exposure by inhalation, ingestion or contamination through open wound. There is no big difference between the work with soft β-emitters and handling the poisons or infectious materials.

The degree of protective measures is proportional to the amount of activity that is handled. The laboratories are categorized – from I. category (lowest degree of measures) to IV. category (highest protection). The principal isolation device used for isolation of workers from radiotoxic materials in the laboratories of I. and II. category is radiochemistry fume hood. All fume hoods in the refurbished IOCB fulfil the requirements posed on radiochemistry fume hood. The activities handled on IOCB (including the synthesis of labelled compounds) are such that work can be performed in laboratories of I. category (application of labelled compounds in biochemical experiments) or of II. category (syntheses of labelled compounds). That is why the equipment of laboratories of categories III. and IV. will not be discussed here.

[*] Average thickness of epidermis is 0.5 mm, on hands and foots it is up to 1 mm thick.

The important value for planning the experiment is the **maximal authorized activity** that can be handled at one workplace. The calculation of maximal authorized activity is based on the maximal dose of ionizing radiation which could obtain exposed worker in the case of accidental loss of control over the source of ionizing radiation and which is no threat to his health. Maximal authorized effective doses are set as 1/10 of experimentally estimated safe levels. The radiotoxicities of radionuclides are very different according to type and energy of emitted radiation (in calculation they are characterized by the intake conversion factor $\mathbf{h_{inh}}$) and consequently maximal authorized activities are also different. Another decisive factor is the isolation capacity of the workplace expressed as effectivity factor in comparison with the radiochemistry hood. Maximal authorized activities for workplaces in I. category laboratory are tabulated in Annexe 1. of the Operation manual.

Monitoring of laboratories is very important part of the system of protection against ionizing radiation. Monitoring means the checking of radioactive contamination of laboratory outside the workplaces. The rise of contamination outside the proper workplaces – fume hoods – is signalling their malfunction or unsuitable operation protocol. By early recognition of protection devices malfunction it is possible to prevent higher internal exposures of workers. On the laboratory floor the squares 10x10 cm to be checked are marked by special waterproof marker (see Fig. 4). Regularly once a week these squares are checked for surface contamination by large window contamination monitor. Where compounds labelled by radionuclide ^{3}H are used the contamination must be controlled by swipes – the surface of the square is rubbed by cotton swab wetted by water then the swab is placed in scintillation vial and scintillation cocktail is added. Activity is assayed on LSC spectrometer.

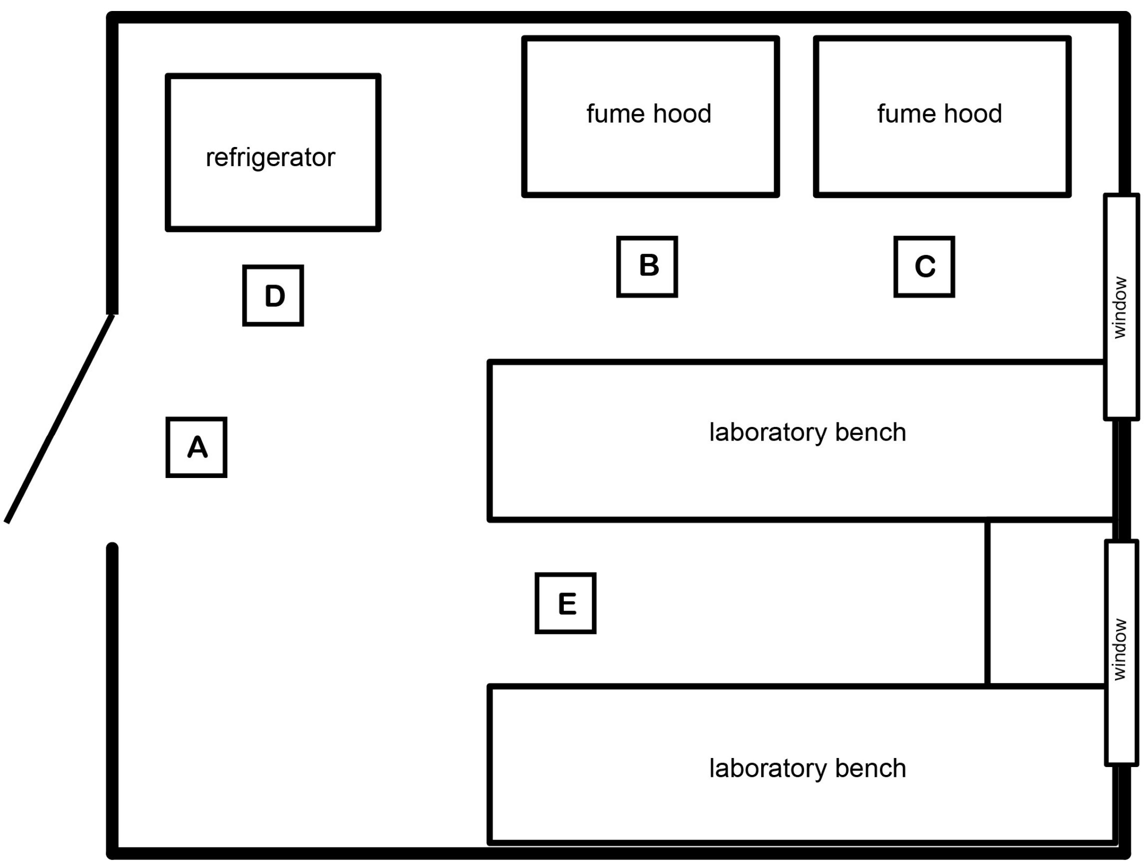

Fig 4. Monitoring of contamination of Supervised area.

The results of monitoring are kept in the **Monitoring book**. The monitoring of Supervised areas is described in detail Operational manual (Par. 18 to 22). Contamination **Reference levels** and responses if these levels are passed are also described in the referred paragraphs.

10. Clearance levels for soft β-emitters and Radioactive waste.

For the decision whether the waste generated by the experiments with radioisotopes should be treated as radioactive waste or whether it is possible to discharge it as a "common waste" (of course while respecting the rules for separation of waste and rules for dangerous waste discharging) the **clearance levels** are crucial. For the radionuclides most currently used at IOCB the clearance levels as a function of their state of matter are tabulated in Table 3.

(Clearance levels for discharge as a wastewater and for gaseous exhausts (from fume hoods) are given in terms of dose limit – 10^{-2} Sv/m^3 for wastewaters and 10^{-7} Sv/m^3 for gaseous exhausts. For individual radionuclides the clearance levels in terms of activity are calculated as quotient of dose limit for wastewaters to ingestion factor h_{ing} or quotient of dose limit for gaseous exhausts to inhalation factor h_{inh})

Table 3. Clearance levels for soft β-emitters regardless of total activity released.

Radioisotope	Clearance level						
	for sorting out from the Supervised area			for discharging			
	specific activity a)		surface activity b)	waste water		gaseous exhausts	
	[kBq/kg]	[microCi/kg]	[Bq/100 cm^2]	[MBq/m^3]	[mCi/m^3]	[Bq/m^3]	[nCi/m^3]
^{3}H	100	2.7	40	240	6.49	2439	66
^{14}C	1	0.03	40	17	0.47	172	5
^{35}S	100	3	40	13	0.35	143	4
^{33}P	1000	27	40	42	1.13	-	-
^{32}P	1000	27	40	4	0.11	-	-
^{125}I	100	2.7	40	0.7	0.02	7	0.2
a) specific activity of solid matter and solid subjects							
b) surface contamination of apparatus, furniture							

For limited amounts of solid radioactively contaminated waste lower or equal to 1,000 kg the clearance levels are higher. At the same time the maximum total activity that can be disposed in this manner is limited, too. This higher clearance levels are in the Table 4.

Table 4. Clearance levels for limited amounts of solid contaminated waste

Radionuclide	specific activity		maximal total activity	
	[MBq/kg]	[mCi/kg]	MBq	mCi
^{3}H	1 000	27.03	1000.0	27.027
^{14}C	10	0.27	10.0	0.270
^{35}S	100	2.70	100.0	2.703
^{33}P	100	2.70	100.0	2.703
^{32}P	1	0.03	0.1	0.003
^{125}I	1	0.03	1.0	0.027

Radioactive waste is sorted according to several criteria. The final processing of radioactive waste is expensive but correct sorting leads to substantial economies.

According to state of matter the radioactive waste is sorted to:

- liquid
- solid

And according to its radioactivity:

- **Very short lived waste (VSLW)** – after prolonged storage (not exceeding 5 years) its activity is lower than discharge limit for a given radio nuclide and type of waste. As a rule of thumb it should be remembered that after the 10 half times period the residual activity represents 1/1000 of the initial activity
- **Low level and intermediate level waste (LLW and ILW)**
  - **short living waste** - all radio nuclides present in the waste must have half time shorter than 30 years
  - **long living waste –** contains radio nuclides with half-life longer than 30 years
- **High level waste** – during the temporary and/or ultimate storage of this waste the appropriate arrangements must be made to dissipate the heat produced by radioactive disintegrations – this is the waste left after reprocessing of nuclear fuel and this type of waste is not produced at IOCB

How to treat the radioactive waste is described in Operational manual in detail.