Protection from Ionizing Radiation.

1. Relevant Czech legislation.

The principle law which regulates all applications of ionizing radiation is the **Atomic Act** issued in 1997 (Item No. 18/1997, amended in 2002). The Atomic Act gives definitions of principle terms and rules 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 the state created the Radiation Safety Agency (in Czech: Státní úřad pro jadernou bezpečnost (**SÚJB**)).

Bylaw No. 307/2002 gives details about radiation protection when working with radioisotopes. It is based on **Directive No. 96/29/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.

2. Principal terms.

The bellow presented principal terms and their definitions are partly taken from the English version of **Directive No. 96/29/EURATOM** ([a]) or from **SAFETY SERIES No. 115,** International Basic Safety Standards for Protection against Ionizing Radiations and for the Safety of Radiation Sources, IAEA, Vienna, 2003 ([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 nanometer or less or a frequency of 3×10^{15} Hertz or more capable of producing ions directly or indirectly.

Source [a] **-** An apparatus, a radioactive substance or an installation capable of emitting ionizing radiation or radioactive substances.

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 the bequerel (**Bq**). Another frequently used unit is millicurie (**mCi**). 1 mCi = 37 MBq

Radioactive substance [a] **-** Any substance that contains one or more radionuclides the activity or concentration of which cannot be disregarded as far as radiation protection is concerned.

Sealed source [b] **-** Radioactive material that is permanently sealed in a capsule or is closely bounded and in a solid form. The capsule or material of a sealed source shall be strong enough to maintain leak tightness under the conditions of use and wear for which the source was designed, also under foreseeable mishaps.

Unsealed source [b] – A source that does not meet the definition of a sealed source.

Radiation Protection [c] – An arrangement of technical and organizational resources destined to limit irradiation of persons and to protect the environment.

Exposed worker [c] - Any person which could be or is irradiated while effecting its profession, disregarding the fact being an employee or having any other legal status.

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

Exposed worker, category "B" [a] - those exposed workers who are not classified as exposed category "A" workers.

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 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, and exposure to which is not excluded from the Standards.

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 [b] - 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.

Radiological emergency of I. degree [c] – An accident the consequence of which is or could be unacceptable irradiation of exposed workers or other persons and intolerable discharge of radioactive substances to the laboratory space. The exposed workers are able and have resources needed to manage the situation themselves. The declaration of Radiological emergency of I. degree must be reported to SUJB in 24 hours at latest.

External exposure [b] – Irradiation by sources outside the body.

Internal exposure [b] - Irradiation by sources inside the body.

Gray (Gy) [a] - The name of the unit of **absorbed dose** (that is the absorbed energy). One gray is equal to one joule per kilogram: 1 Gy = 1 J kg^{-1} .

Equivalent dose [b] - The absorbed dose in tissue or organ weighted for the type and quality of radiation; the weighing factor is 1 for gamma and beta radiation, 5 to 20 for neutrons (depending on their energy) and 20 for alfa radiation (and any other big particles).

Sievert (Sv) [a] – The special name of the unit of equivalent or effective dose. One sievert is equivalent to one joule per kilogram: 1 Sv = 1 J kg^{-1}.

Effective dose [b] - The sum of the weighted equivalent doses in all the tissues and organs of the body from internal and external irradiation. The response of different tissues and organs of the human body to the same equivalent dose is not the same (e.g. for skin the weighting factor is 0.01, for muscles and liver 0.05, for lungs 0.12, for gonads 0.20).

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 vapors) by exposed workers; 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. 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 1. 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		

4. Classification of the sources.

For the purpose of the health risks evaluation based on the amount of activity handled Czech bylaw 307/2002 defines five classes of sources. For the labeled compounds, which are all unsealed sources, the decisive is amount of activity and specific activity (activity per mass unit). As the type of disintegration and energy of emitted particles varies from one radioisotope to another, so varies the values for their classification.

* Range is the distance which travels the particle with the E_{max} in given material. The particle is loosing gradually all its initial energy, the greatest fraction of the energy is lost at the end of the trajectory.
The energy of gamma radiation diminishes exponentially with the distance but never reaches zero level as in the case of particulate ionizing radiation. 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.

Unimportant source – Either the activity and specific activity is less or equal to exemption level. Exemption levels* for the chosen radioisotopes are given in Table 2.

Small source – Either its activity or specific activity is higher than exemption level but no more than 10 times.

Simple source – For the labeled compounds any amount of activity exceeding the exemption level more than 10 times.

Just for completeness – there are also **important sources** (e.g. therapeutic gamma sources) and **very important sources** (e.g. nuclear reactor).

Table 2. Exemption levels for frequently used radioisotopes

Radioisotope	Exemption level			
	Activity		Specific activity	
	[MBq]	[mCi]	[MBq/kg]	[mCi/kg]
^{3}H	1000	27	1000	27
^{14}C	10	10.3	10	0.3
^{35}S	100	2.7	100	2.7
^{33}P	100	2.7	100	2.7
^{32}P	0.1	0.003	1	0.03
^{125}I	1	0.03	1	0.03

5. Discharge limits 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 separate waste and dangerous waste dischaging) the **discharge limits** are crucial.

Discharge limits state maximal admissible levels of radioactivity introduced from the Supervised and Controlled areas to the environment.

Please note that the discharge limits are much lower than exemption levels!

For the evaluation of contamination and surface contamination of solid matter, apparatus, furniture etc., the radioisotopes are sorted to four classes of radio toxicity. Among the Class IV radioisotopes, the least radiotoxic ones, we can find ^{3}H, ^{33}P and ^{35}S. In Class III are filed ^{14}C and ^{32}P. Due to its gamma radiation the ^{125}I is in the Class II.

Discharge limits for waste water and gaseous exhausts are calculated as quotient of the given dose limit (10^{-2} Sv m^{-3} for waste water and 10^{-7} Sv m^{-3} for exhausts) and the corresponding h_{ing} (waste water) or h_{inh} (exhaust). In Table 3. are the values for the soft β−emitters of our interest and for ^{125}I.

* Exemption levels are internationally recognized and are important for legal purposes. If the total amount of activity in the possession of fictitious person does not exceed the corresponding exemption level its handling is exempted from reporting to authorities and the licence for handling radioactive sources in not required.

Table 3. Discharge limits for soft β-emitters.

Radioisotope	Discharge limit						
	for sorting out from the controlled area			for discharging			
	specific activity a)		surface activity b)	waste water		gaseous exhausts	
	[kBq/kg]	[microCi/kg]	[kBq/100 cm^2]	[MBq/m^3]	[microCi/m^3]	[Bq/m^3]	[nCi/m^3]
^{3}H	300		8	238	6435	2439	66
^{14}C	30	0.8	3	17	466	172	5
^{35}S	300	8	30	13	351	143	4
^{33}P	300	8	30	42	1126	-	-
^{32}P	30	0.8	3	4	113	-	-
^{125}I	3	0.08	0.3	0.7	18	7	0.2

a) specific activity of solid matter and solid subjects
b) surface contamination of apparatus, furniture

Radioactive waste is sorted according to its physical state:

- gaseous
- liquid
- solid

and according to its radio activity:

- **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 remebered 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

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

As stated above, beta radiation on the contrary to gamma radiation can be completely stopped by definite not very thick sheet of material. The beta particles emitted by ^{3}H, ^{14}C and ^{35}S are completely absorbed in outermost horny layer of skin called epidermis* which is one hundred

* The mean thickness of epidermis is 0.5 mm. It varies from 0.1 mm at the eyelids to 1 mm on the palms and soles.

times more resistant to radiation than other parts of the body. Thus the blinding during the work with these radioisotopes is not necessary. On the other hand beta radiation of the ^{32}P penetrates as deep as 8 mm to living parts of the skin and could damage it as well as the organs placed just under the skin. That is why it is necessary to use during the work with the ^{32}P the acrylic glass blinding of thickness 8 mm at least.

The principal point of the radiation protection is thus elimination of intake of labeled compounds by inhalation, open wound or orally. At this point there is no difference between the work with soft β-emitters and work with poisons or infectious material.

The scale of protecting measures is proportional to the amount of activity handled. The Czech bylaw 307/2002 recognizes four categories of laboratories. The principal protective element (or isolation device, by the language of the bylaw) in the laboratories of I. and II. category is radiochemical hood*. For the synthesis and application of labeled compounds on scale usual nowadays the laboratory of III. nor IV. category is not needed and they will not be dealt in this text.

The personal protecting devices used in laboratory of I. category are lab coat, gloves (rubber, PVC, PE) and when working with vacuum devices the protective goggles.

In the laboratory of II. category to the above mentioned devices adds the complete change of the civil dress for laboratory one.

6.1. Maximal activities handled on a workplace.

The limit for the effective dose of ionizing radiation admissible for exposed workers without health consequences is 1/10 of that estimated from data collected during the years of the application of ionizing radiation. The limit amounts of activity taken to experiments which guarantee not surpassing the permissible effective dose for exposed workers under normal operation conditions and also in the situation when the control over the radioisotope is lost (e.g. breakage of flask containing the labeled compound) are calculated. The calculation takes into account the h_{inh} of the radioisotope, isolation properties of the workplace and nature of the experiment. Every worker has to consult these limits when planning the experiment. For the most frequently used radioisotopes these limits in force for the laboratory of I. category are arranged in the following tables. The term **wet chemistry** denotes handling of solutions of non-volatile compounds labeled by corresponding radioisotope.

* The radiochemical hood must have washable walls and the bottom with elevated rims. Hood in the form of wooden construction over laboratory bench with glass panels which is very often seen in Czech laboratories yet is considered by the bylaw as common chemical hood.

Table 4. Maximal activities for handling ^{3}H in laboratory of I. category

Nature of handled substances	A*max* for standard workplace					
	radiochemical hood		common chemical hood		laboratory bench	
	[GBq]	[Ci]	[GBq]	[Ci]	[GBq]	[Ci]
common	3 333	90	333	9	33	0.90
wet chemistry	166 667	4 505	16 667	450	1 667	45
volatile liquids	55.6	1.5	1	0.15	0.56	0.015

Table 5. Maximal activities for handling ^{14}C in laboratory of I. category

Nature of handled substances	A*max* for standard workplace					
	Radiochemical hood		common chemical hood		laboratory bench	
	[GBq]	[Ci]	[MBq]	[mCi]	[MBq]	[mCi]
common	103	3	1 034	28	103	3
wet chemistry	5 172	140	51 724	1 398	5 172	140
volatile liquids	2	0.05	17	0.5	2	0.05

Table 6. Maximal activities for handling ^{32}P in laboratory of I. category

Nature of handled substances	A*max* for standard workplace					
	Radiochemical hood		common chemical hood		laboratory bench	
	[GBq]	[mCi]	[MBq]	[mCi]	[MBq]	[mCi]
common	19	507	188	5	19	0,5
wet chemistry	938	25 338	9 375	253	938	25
volatile liquids	0.3	8	3	0.08	0.3	0.008

Table 4. Maximal activities for handling ^{35}S in laboratory of I. category

Nature of handled substances	A*max* for standard workplace					
	Radiochemical hood		common chemical hood		laboratory bench	
	[GBq]	[Ci]	[MBq]	[mCi]	[MBq]	[mCi]
common	545	15	5 455	147	545	15
wet chemistry	27 273	737	272 727	7 371	27 273	737
volatile liquids	9	0.25	91	2.5	9	0.25

Table 8. Maximal activities for handling ^{125}I in laboratory of I. category

Nature of handled substances	*Amax* for standard workplace					
	Radiochemical hood		common chemical hood		laboratory bench	
	[GBq]	[Ci]	[MBq]	[mCi]	[MBq]	[mCi]
common	4	0.116	43	1	4	0.116
wet chemistry	214	6	2 143	58	214	6
volatile liquids	0.07	0.002	1	0.02	0.07	0.002

6.2. Supervised Area and Controlled Area.

Supervised Area is delimited in those laboratories or other spaces (e.g. connecting corridors) where under normal operation conditions or foreseeable deviations from normal operation conditions could the effective dose of workers exceed the common limit for population (1 mSv/year). Access to supervised area is not restricted but handling with radioisotopes is permitted only to authorized personnel. All laboratories of I. category are automatically supervised areas. The entrance to the Supervised area is indicated by the following warning sign (Supervised area with sources of ionizing radiation):

Although the category of small sources prevails, many used sources are simple sources. From this fact follows the duty of regular monitoring of the supervised areas in our institute (see bellow).

Controlled Area is delineated in laboratories where under normal operation conditions or foreseeable deviations from normal operation conditions the effective dose of workers could exceed the 3/10 of permissible value for exposed workers (upper limit of annual effective dose for exposed workers is 50 mSv/year). Access to the controlled area is restricted. The entrance of exposed workers "A" and "B" is not monitored but only the exposed workers "A" are authorized to work in controlled area. The entrance of other persons is registered in the Book of visitors and the visiting person must always bee accompanied by exposed worker. The surface contamination monitoring is obligatory.

The effective dose obtained by exposed workers during the stay in the controlled area is monitored by personal film dosimeters. Exposed workers pass every year medical examination. In our institute the controlled area is delineated only in the Laboratory of Radioisotopes.

The entrance to the Controlled area is indicated by the following warning sign (Controlled area with sources of ionizing radiation; Entrance of unauthorized personnel prohibited):

6.3. Monitoring of surface contamination.

Needless to say that working with important activities requires continuous tracing of the activity on workplace and control of the contamination of workplace once the work is finished. The results of measurements are not recorded. In Table 9. are the reference levels – i.e. the acceptable levels - of the surface contamination of workplace in I. category laboratory. If the contamination is higher, the workplace must be washed until the reference levels are reached.

Table 9. Reference levels for workplace contamination in laboratory of I. category.

Radioisotope	^{3}H	^{35}S	^{33}P	^{55}Fe	^{14}C	^{32}P	^{51}Cr	^{125}I
Reference level [kBq/100 cm^2]	30	30	30	30	3	3	3	0.3

The **regular monitoring of surface contamination** outside the workplaces in the laboratory has several objectives:

- disclose the malfunction of protection devices in the laboratory (hoods, hermetical boxes etc.)
- disclose the accidental spill of radioactivity outside the workplace which would otherwise pass unnoticed
- prevent the intake of stirred radioactive dust particles by exposed workers
- prevent the spreading of radioactivity outside the Supervised area or Controlled area

The results of this regular monitoring are recorded in the "Monitoring book". This book is kept for every Supervised Area or Controlled Area.

The control surfaces of 100 cm^2 are marked on the floor of the laboratory at the entrance and in front of hoods, freezers etc. (the number control surfaces depends on number of workplaces in the laboratory). Once a week* the activity of these surfaces is measured. The results are

* This interval applies when the radioisotopes are handled every week. In the case when the intervals between the works with radioactivity are longer, it is sufficient to exercise monitoring only after finishing the work.

recorded into "Monitoring diary". The radioactivity can be measured either by taking the swipes* or the surface can be measured directly with the contamination monitor with large window detector.

The measured values of surface contamination are compared to reference levels for the given radioisotope (the radioisotopes from the same radio toxicity class have the same reference levels). In the Table 10. are reference levels which apply for the Supervised area.

Table 10. Reference levels for surface contamination in the laboratory of I. category.

	^{3}H	^{35}S	^{33}P	^{55}Fe	^{14}C	^{32}P	^{51}Cr	^{125}I
Recording level [kBq/100 cm^2]	3	3	3	3	0.3	0.3	0.3	0.03
Investigation level [kBq/100 cm^2]	10	10	10	10	1	1	1	0.1
Action level [kBq/100 cm^2]	30	30	30	30	3	3	3	0.3

Recording level corresponds (with the exception of wipes) with the threshold of the contamination monitors.

Investigation level is still acceptable level of contamination. The reason of this higher contamination should be investigated as it points to some problem and further increase of contamination could result in unacceptable level.

Action level is unacceptable level of contamination and decontamination must be done without delay.

* The surface is wiped by the cotton swab moistened by water (or other solvent or solvent mixture, depending on the nature of compounds handled), the swab is put into the scintillation vial, the scintillation cocktail is added and the activity is measured in liquid scintillation spectrometer.