Fachverband für Strahlenschutz e.V.
Für Deutschland und die Schweiz
Mitgliedsgesellschaft der IRPA
International Radiation Protection Association

Radiation protection today – success, problems, recommendations for the future

The «Club of the Philosophers» of the
German-Swiss Association for Radiation Protection

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Abstract

During the last years, manifold concerns have been raised regarding the actual status of radiation protection. The concerns apply likewise to scientific and technical aspects of the regulations and their implementation and – in particular – to the perception of radioactivity, radiation, and radiation protection by society. The German-Swiss Association for Radiation Protection (Fachverband für Strahlenschutz, FS for short) has therefore established a working group to discuss questions of principle of radiation protection and to develop recommendations for its future development.

This paper is organized in the following way. The first chapter summarizes the recommendations, the following chapters explain in detail the recommendations and their rationale. The explanations start in chapter two with a retrospect to the history of radiation protection demonstrating that **radiation protection made a long way to achieve safety – a success story**. Radiation protection provides the basis for the safe handling of radioactivity and radiation for the benefit of humankind. Given the possible health effects of radioactivity and radiation, good practice of radiation protection will be definitely needed also in the future. Radiation protection should be understood as an integral part of safety culture and should be lived as such with the final goal to achieve and maintain safety.

The next chapter deals with the natural radioactivity and radiation and its associated risk. The natural radiation exposure and its variability with space and time provide **a benchmark for radiation protection** for the assessment of any additional exposure caused by human activities. Natural radioactivity and radiation are omnipresent and to a large degree unavoidable. The inferred natural radiation risk – let it be hypothetical or epidemiologically recognizable – is a nature-given part of life. The unavoidable part of the natural radiation exposure sets a natural lower limit to the efforts of radiation protection for minimizing doses and risk. Reducing individual contributions to the radiation exposure far below this natural limit is not

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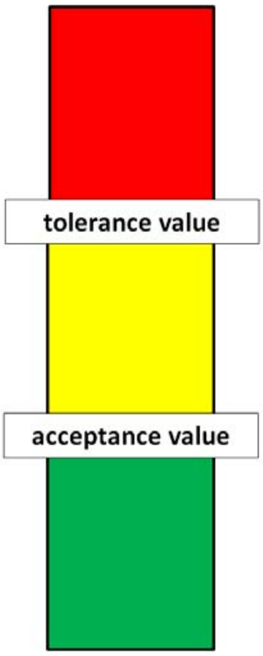
reasonable, wastes resources and increases the fears of the people. What counts is always the total dose a person receives.

In the last chapter the discomfort of the practitioners of radiation protection is analyzed in depth, theses to overcome the related problems are presented and recommendations for the future development of radiation protection are made and substantiated.

A German draft of this position paper was given to the members of the FS for consultation and the predominantly positive responses were considered in the final version. The board of the FS has declared the paper as a position of the FS, which herewith is internationally presented for discussion.

1. Summary of the recommendations for the future development of radiation protection

Ionizing radiation and radiation risk	
Safety instead of risk	Radiation protection accomplishes safety and reduces risks and fears. Practitioners of radiation protection care for safety when handling with radiation and radioactivity. They are experienced, know their profession and take regularly part in professional training. They strive towards neutrality and objectivity. They advocate for transparency and understandability by laypersons of the regulatory system of radiation protection and of the associated protective measures.
Radiation dose, effects, and limits	
Considering total doses instead of individual dose components	Whenever possible, total doses shall be given and assessed in a holistic way with respect to radiation effects and risks; considering in particular the comparison to the natural radiation exposure and its variations with space and time.
Clear definition and distinction of doses	For the communication with the public clear and understandable statements are required. Particular care has to be taken if dealing with hypothetical doses and calculated, hypothetical deaths. This applies also to dose values; i.e. – whether they are measured or calculated or whether they are prognoses, – whether they are based upon realistic or conservative assumptions, – whether they are real doses, received by humans, or hypothetical doses, which a human possibly could receive at some time, – whether it is the total dose or just a component of it, – whether it is an effective dose, an organ equivalent dose, or an absorbed dose. Calculations of hypothetical contributions to the dose are mere planning tools and do not represent actual exposures. Hypothetical dose contributions have to be clearly distinguished and marked as such. In most cases, they also have large uncertainties which – whenever meaningful possible – should be given.
No misuse of the collective dose	The collective dose provides an important planning tool for the optimization of radiation protection in countably defined group of persons; it is not a tool for calculating hypothetical cases of morbidity or death. ICRP has warned against calculating hypothetical deaths in the low dose region: *”It is not appropriate, for the purpose of public health planning, to calculate the hypothetical number of cases of cancer or heritable disease that might be associated with very small*

	radiation doses received by large numbers of people over very long period of time." (ICRP103 (2007), p.51).
LNT-hypothesis and the multiplicative risk model	The LNT model has to be better explained, in particular with respect to the uncertainty of statements based on it; that it potentially overestimates the risk in the low dose region, but that it is – based on today's knowledge – practical and fit for purpose for radiation protection. In addition, the multiplicative dose risk model (based on a linear-quadratic model) has to be better explained; in particular with reference to the spontaneous cancer risk and its variability.
Consequent use of ALARA	The «*social and economic*» maxim of the ALARA principle shall be consequently followed in the different exposure situations as well its implementation in different cultures and societies considered.
Limits, reference values, dose constraints etc.	The system of limits, reference values, constraints, intervention levels, etc. is too complex and cannot generally be communicated. Quantities of radiation protection, i.e. doses, must be understandable and traceable for the entire society including politicians, decision makers, teachers, and journalists as multiplicators. Such quantities shall convey safety and not unsettle people. A traffic light scheme should therefore be systematically applied. Such a scheme is understood by everybody.
A traffic light scheme of radiation protection as a tool for communication	 **The tolerance value is equivalent to the dose limit in planned exposure situations or to the upper reference value in existing and emergency exposure situations. Exposures above the tolerance value should be considered not tolerable or inacceptable.** **In the yellow region exposures are deemed as tolerable if everything is done to reduce exposures taking societal and economic aspects into account: ALARA.** **The acceptance value is equivalent to the unavoidable part of the natural radiation exposure. Given the variability of the unavoidable natural doses 10% of the acceptance value should be a trivial dose.** **For clarification:** **Optimization is reduction under constraints.**
No further lowering of limits	According to today's knowledge a further lowering of limits is not meaningful because the present limits are already low compared to the natural doses. However, the system of limits is not consistent with respect to the regulation of natural and artificial radiation and radioactivity. In spite of that, the actual dose limits guarantee good protection according to the status of science and technology. Too low limits would just convey a wrong feeling of dangerousness.
Consistent regulations for Radon	The international organizations dealing with radiation protection did not perform their task with respect to Radon. The attempt failed to provoke fears and uncertainties in the public regarding something natural and inevitable with which mankind is living since the beginning of time. Such a discrepancy has to be avoided as a matter of principle! WHO, ICRP, IAEA and other national and

	international institutions of radiation protection have to develop a consistent and practicable concept with regard to the dosimetry and protection with harmonized regulations, which can be communicated in simple terms.
Dose to the lens of the eye	The new recommendations and regulations regarding the dose to the lens of the eye are regarded as not reasonable. In practice, they cause disproportionate surveillance efforts in an exposure situation in which high doss can be avoided with relatively simple protective measures. Moreover, cataracts of the eye today can be successfully treated. The new regulations for limiting the dose to the lens of the eye should therefore be withdrawn.
Practical radiation protection	
Avoid unnecessary conservativities	Conservative assumptions in dose calculations shall be avoided as far as possible and realistic numbers for doses and risks shall be stated. The multiple and stringed-together application of conservative assumptions frequently causes completely wrong results and therefore is to avoid.
Emphasize the principle of justification	According to ICRP 103 every decision which changes an exposure situation shall cause more benefit than harm. This principle is also important for the practice of radiation protection, e.g. the deaths due to evacuation during the Fukushima accident. It can also be easily communicated to laypersons and can help to repel requests for not justified protective measures.
Optimization must have a lower limit	Optimization is one of the three basic principles of radiation protection; but it must have a lower limit. Reducing doses below 0.1 mSv per year (for the general public) resp. below 1 mSv per year (for occupationally exposed persons) is not regarded as reasonable in practical operational radiation protection. For optimization during planning of extensive work jobs with noteworthy collective dose – e.g. a comprehensive revision of a large pump in a nuclear power plant which needs several people – 1 person-mSv is to be regarded as a sufficiently low lower limit of optimization.
Disclose the limitations of epidemiological studies	Epidemiological studies are important, but they have also their limitations. In the low dose region the informative value is limited due to statistical uncertainties, one the one hand, and because it is practically impossible to find a control population on our planet which is identical with respect to all possible influencing factors, on the other hand. Consequently, a complete uncertainty analysis is practically impossible.
Implementation of a traffic light scheme of radiation protection	Radiation protection can easily be explained by a traffic light scheme. Such a scheme is understood by anybody: exposures in the RED region are not acceptable and require protective action, in particular if limits are exceeded. In the YELLOW region exposures are considered as tolerable. It is the region of optimization considering all particular aspects. Exposures in the GREEN region are considered as acceptable and do not require protective measures.
Allow reason to prevail	Practitioners of radiation protection should not follow the regulations in a formalistic way. By applying the regulations, they shall act in a reasonable and appropriate using common sense resting upon their education and experience. Practitioners of radiation protection must not be reduced to stubborn correction officers who just look for compliance with rule and do not care for the protection against threats. The experiences of practitioners should be incorporated during the establishment of regulations and guidelines and margins of discretions should be defined. Sufficient resources have to be allocated in order to provide the opportunity that all actors in radiation protection are sufficiently educated and can educate themselves in a professional and skilled manner, so that they can work re-

	sponsibly for a reasonable and appropriate implementation of radiation protection.
Correct interpretation of measurements	Measurement techniques have made enormous progress during recent decades. Minute fractions of a Becquerel per sample volume can be exactly determined. However, the fact is that not everything what is technically measureable is also safety relevant. A high measuring sensitivity makes sense if the task is to determine certain quantities as low and exactly as possible at only a few locations in a country in order to document also minor long-term trends and changes of environmental radioactivity.
Coping with emergency situations	
Emergency situations	The information of the public in emergency exposure situations is in need of improvement. This holds also for emergency preparedness. The information has to become more understandable and traceable, in particular in the following areas: crisis management, protection concept, dynamic intervention and reference values, and trans-border collaboration for the mitigation of a radiation incidence or accident. The public has to be informed promptly about cause, progression, and effects of a radiation incident or accident as well about the surveillance of the effects and the protection concept for the affected staff and the action force. Medical and psychological care and general support has to be provided for the persons concerned also with respect to the non-radiological consequences and their mastering. These aspects should be considered already during planning and organization.
Flexibility in emergencies	Already for emergency preparedness and quite so in the case of a radiological emergency the system of flexible reference values and intervention levels has to be made clear to the public. In such an emergency, the information has to be trans-nationally harmonized and adjusted to the progress of the event. The latter is necessary to allow for a step-wise return to normality.
Handling of radiation fears	It is necessary to develop a strategy to deal with radiation fears. Fear of radiation frequently is more relevant for the health than the radiation itself. Measures have also to be planned and installed for coping with the non-radiological consequences of a radiological emergency (posttraumatic stress disorder) and a respective communication and information concept must be prepared. After the Chernobyl accident and even more after the Fukushima accident the non-radiological effects were grossly underestimated and not systematically documented. It is likely that they were more important than the radiation-induced effects.
Communication with and information for the public	
Professional design of communication	In case of need, professional persons responsible have to inform the media promptly on behalf of their organizations. For this, they have to be directly cross-linked with the competent authorities and other specialist departments. By such measures it shall be avoided that the self-appointed experts forestall the real experts. In the case of an emergency, it is more important to inform quickly with provisional results of limited accuracy than too late with absolute accuracy and certainty. The honest statement that in the case of an emergency frequently only preliminary results and assessments can be given and that further evaluations have to performed does not make a specialist for radiation protection incredible. In contrast, it allows the public sharing the line of action for overcoming a radiological emergency.

High profile in the media and in education	The visibility of radiation protection in the media has to be improved. There are many investigations, journals, and publications for scientists. However, they do not attract much interest by the media. A strategy is needed to improve the credibility of practitioners of radiation protection for the media, the authorities, and the public. Basic education about radioactivity and radiation at school would considerably facilitate a factual and objective information of the public.
Professional training	The profession of practitioners of radiation protection has to be made more attractive by inventing more levels of qualification. Opportunities for education and professional self-education have to be extended and improved. Respective chairs should be installed at universities.
Intercourse with self-appointed «experts»	A strategy is needed how to cope with self-appointed experts. The goal must be that professionals of radiation protection with their competence and experiences prevail with credible statements in the media and the public and that they are recognized as competent specialists. Training in communication and arguing should be part of the education.

2. The history of radiation protection– a road to more safety

2.1 Introduction

In the course of a more than 100-years history the hazards and risks caused by radioactivity and radiation have been intensely investigated so that today we are having a solid and resilient basis for an internationally accepted system of radiation protection. This system is based on the fundamental principles of justification, optimization, and limitation of exposures. It has achieved the highest possible level of safety for both the occupational exposed ones and the public in general. However, it needs continuous efforts to accomplish good radiation protection, to develop further the system in a sustainable way, and to communicate it to the workforce, the public, and the decision makers.

2.2 The early years and the effects of nuclear weapons

More than 120 years ago X-rays and radioactivity were discovered. Quickly, the opportunities of these phenomena for medical diagnostics and therapy were recognized and their applications spread rapidly. However, already one year after the discovery of the X-rays negative health effects were reported after high exposures (CLARKE und VALENTIN 2009). First, only erythema, a the so-called “X-ray dermatitis”, were in the focus, but soon it became clear that these effects could develop into cancer. This deadly danger had to be met by medical professionals and scientists, but also by companies, who wanted to exploit the opportunities of the new phenomena.

Genetic effects of ionizing radiation were observed as early as in the 1920ties in animal experiments with fruit flies (*Drosophila melanogaster*) by Muller (1927) who obtained the Nobel prize in physiology in 1946 for his discovery. Only after World War II the biological effects of ionizing radiation came into the focus of a broader public. Already during the Manhattan project comprehensive experiences with biological effects of ionizing radiation were obtained, but they were kept classified. The consequences of the atomic bombing of Hiroshima and Nagasaki made the radiation induced health effects universally known.

After an initial search for increased genetic effects, which was without result, first an increase of leukemia and later of solid cancers was observed in the survivors of the bombing. This caused to initiate the *Life Span Study* (LSS) by which the survivors were investigated for the occurrence of leukemia and solid cancers. Today, the results of the LSS performed by the

Radiation Effects Research Foundation (RERF) are the most important data about health effects after external whole body irradiation by neutron and γ-radiation.

The Cold War succeeded World War II and nearly 1 400 test explosions of nuclear weapons were performed of which were about 500 atmospheric explosions with a yield of more than 400 Mt (Megatons) TNT-equivalent. However, high radiation exposures remained restricted to the closer vicinity of the test locations (IAEA 2005). Health effects of people living close to the test areas were largely kept classified and were made public only in the 1990ties.

Globally, the atmospheric test explosions and the subsequent worldwide contamination did not cause detectable health effects (UNSCEAR 2000). On the higher contaminated Northern Hemisphere the radiation exposures remained low; in Switzerland, for instance, the committed effective doses up to the year 1985 were 1.2 mSv (VÖLKLE 1985).

Epidemiological studies of the radiation exposures and effects of the employees of the Majak Atomic Complex and of the population along the Techa River today provide an important basis for the assessment of external and internal exposures at low doses[2] (DAVIS et al. 2015, KRESTININA et al. 2005, 2013, NAIR et al. 2009, SCHONFELD et al. 2013, TAO et al. 2012).

There occurred accidents with deterministic effects affecting both, occupationally exposed workers and members of the public (UNSCEAR 2008b Annex C, ORTIZ et al. 2000, VÖLKLE 2015) and they will continue to occur. To blame are human mistakes and technical faults. They can only be avoided by a technical safety culture and good radiation protection, i.e. a culture of radiation protection.

2.3 Major accidents in nuclear installations

The accidents in the nuclear power plants at Three Miles Island (TMI) in the year 1979, Chernobyl in the year 1986 and Fukushima Dai-ichi in the year 2011 were of particular importance for both the knowledge about radiation-induced health effects and the perception of them in the general public. These accidents are of profound relevance for the biased opinions about nuclear energy and biological effects of ionizing radiation in various populations, in particular in German-speaking countries; e.g. (MICHEL 2015).

On March 28,1979, a core melt-down occurred in block 2 of the nuclear power plant at Three Miles Island (TMI) near Harrisburg/USA as a consequence of a “small” leak in the primary cooling circuit, insufficient process control, and human mistakes. The containment remained intact so that most of the fission products remained in the containment or were withhold by filters. The average dose to members of the public within a 10-miles circuit around the plant was about 0.08 mSv. The highest doses for individual people were about 1 mSv. In several studies health effects as a consequence of the accident were searched for. No radiation-induced effects were found (HATCH et al. 1991; LEVIN 2008), but psychological effects such as a consequence of anxiety and unsettledness were observed (DOHRENWEND et al. 1981).

On April 26, 1986 block 4 of the nuclear power plant at Chernobyl in Ukraine exploded. In the course of a routine experiment an uncontrolled excursion of power occurred because of inherent safety deficits, design errors of the reactor type, management faults, and human mistakes. The reactor core lay open after the explosion, a graphite fire commenced and the residual core melted. A total of 5.3×10^{18} Bq of radioactivity was released (UNSCEAR 2000).

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[2] The term „low doses“ is defined in chapter 4.4.

In short course about 115 000 persons were evacuated. The evacuees received thyroid doses of up to a few Gy and effective doses up to e few times ten mSv. The not evacuated population in the highly contaminated regions received the highest exposures. Out of 134 emergency workers who developed acute radiation syndrome (ARS; occurs above about 2 Gy) 28 died after the accident due to ARS. Of the more than 500 000 clean-up workers, usually called liquidators, 300 000 received average effective doses of 146 mSv in 1986. In 1987, about 138 000 worker were exposed to 96 mSv on the average. In the highly contaminated regions of Belarus, the Ukraine and the Russian Federation, children received thyroid doses up to a few times ten Gy since no emergency protective measures were recommended or performed, such as e.g. thyroid blocking by administration of stable iodide. These high thyroid doses caused a strong and pertinent increase of thyroid cancer in those exposed in childhood.

On March 11, 2011 at 14:46 LT, a marine earthquake of magnitude 9.0 occurred offshore the coast of Tohoku/Japan in the Pacific Ocean. About 1 hour later, a 7 m – 15 m high tsunami wasted the coastline. There were more than 20 000 deaths and missing and 380 000 people had to be evacuated because of the earth quake and tsunami (UNSCEAR 2014).

Three blocks of the nuclear power plant at Fukushima Dai-ichi were safely shut down during the earth quake. However, the tsunami flooded the plant and destroyed the emergency power supply, the supporting cooling-water buildings, and the seawater entrance structures. This led to a complete „station black-out“. In succession the cores of three reactor blocks melted, four hydrogen explosions destroyed four reactor buildings, and the containment of block 2 failed.

The releases of radioactivity, however, remained about one order of magnitude below those of the Chernobyl accident because of the construction type of boiling water reactors. They consisted mainly of short-lived rare gas radionuclides, radioactive iodine isotopes, as well as ^{134}Cs and ^{137}Cs. Regions of the Fukushima Prefecture and of adjacent prefecture were noteworthy contaminated. 78 000 people had been evacuated in time out of the 20 km circle around the nuclear power plant; later more people were evacuated out of the higher contaminated regions in the north-west of the plant. Thyroid doses remained below 50 mSv and the effective life-time doses of the inhabitants of Fukushima Prefecture will remain below 20 mSv (UNSCEAR 2014).

No deterministic effects were observed among the workers and the public, recognizable stochastic effects of the radiation exposure, such as leukemia and solid cancers, are not to be expected (UNSCEAR 2014, WHO 2012, IAEA 2015). However, the partially overhasty evacuation of a total of 146 520 people and the long-term personal living conditions of the evacuees caused more than 1 000 not radiation-induced premature deaths in the Fukushima Prefecture (Japan Times 20. Februar 2014. http://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/fukushima-accident.aspx).

After large reactor accident such as at Chernobyl and Fukushima, the evacuees and the emergency workers suffer of a post-traumatic stress syndrome, they are stigmatized and became socially excluded. Uprooting, the loss of their homeland as well as of social connections add to this stress. The psychological and social problems of such accidents are the causes of the real health problems. The health problems may well be exaggerated by well-intended but retrospectively questionable measures of radiation protection.

It is to emphasize that these three reactor accidents made it strikingly clear that radiation health effects depend on the dose rates and the doses. This fact is mostly not taken notice of in connection with radioactivity and radiation. Reasons for that are the irrational fears of radioactivity and radiation and that the concept of limits in radiation protection is frequently misunderstood and insufficiently explained in our legal system.

2.4 Natural radioactivity and radiation

Radiation exposures due to natural radioactivity and radiation and their resulting health effect came only relatively late into the focus of radiation protection. RAJEWSKI and coworkers suspected already in the 1930ties that the so-called “Schneeberger Krankheit” a frequent lung cancer of miners known since the middle ages was caused by Radon (^{222}Rn) (ZEMAN and KARLSCH 2013). But only in the beginning of the 1950ties it could be demonstrated that the Radon progeny in deep mines cause extremely high radiation exposures of the lung which are the cause of the lung cancers (BALE 1951).

Epidemiological studies during the following decades demonstrated that many thousands of lung cancer case in Uranium miners worldwide were caused by Radon and its progeny (LUBIN et al. 1995).

For many years it was controversially discussed whether the risk of lung cancer observed in miners can be transferred to the radiation exposure due to Radon and its progeny in homes. This risk proved to be real, but could be recognized only in extremely large populations (DARBY et al. 2005; KREWSKI 2005, 2006; LUBIN 2004).

A special aspect of the Radon problem is that the radiation exposure due to Radon and its progeny is already relatively high at normal Radon concentrations. Today the mean Radon concentration in homes is 50 Bq/m^3 with a resulting effective dose rate of about 1 mSv per year in Germany; the equivalent dose rate to the lung is about 10 mSv per year. In Switzerland, an average annual effective dose due to Radon in homes of 3.2 mSv was reported for a mean Radon concentration of 75 Bq/m^3 in 2009 (BAG 2010). The apparent difference between Germany and Switzerland is that Switzerland used the new dose conversion coefficients according to the „Statement on Radon“ of the ICRP of November 2009 while Germany still uses the old conversion factors.

Many parts of the world population receive elevated radiation exposures from natural radioactivity and radiation (e.g. aircrews due to the cosmic radiation, workers in water works due to Radon, and many other more). UNSCEAR is presently elaborating a report on the biological effects of low doses and low dose rates as they occur due to elevated natural radioactivity in various regions of the world or due to artificial radionuclides along the Techa River in West Siberia. The up to now results indicate that the risks caused by these exposures are not in contradiction to the risks extrapolated from the risks seen in the Life Span Study. However, due to the large statistical uncertainties no unambiguous statements can be made in the dose region of extrapolation.

2.5 Today’s knowledge about the biological effects of ionizing radiation

Even if – after more than 50 years of research – one is lacking deeper insight into the genesis of stochastic effects in particular of cancer and leukemia in general, their risks can be sufficiently quantified to be able to implement radiation protection in a responsible and reasonable way. The estimates of the stochastic risks did not change significantly during the last three decades.

Today’s knowledge and ignorance about radiation exposures and their induced health effects were summarized by UNEP (2016) in a highly recommended booklet. According to this booklet the radiation induced effects can be summarized as follows (Fig. 1):

- At doses **above 1.000 mSv** the exposed individual will show clinically manifested health effects such as sterility, erythema, cataracts, and the acute radiation syndrome. These so-called deterministic effects are characterized by the facts that the severity of the effects increases with dose and that there is a threshold below deterministic effects will not occur.

- Below a dose range of **500 mSv to 1.000 mSv** deterministic effects are not to be expected. This is the region of stochastic effects such as leukemia and solid cancers for which the probability of incidence – however not the severity of the disease – can be estimated. The probability of the stochastic effects increases linear or linear-quadratic with dose. The leukemia of solid cancer risks can only be observed in epidemiological studies on large populations. Whether or not a cancer is caused by radiation or other agents cannot be decided and can only supported by probability statements.
- Below about **100 mSv** epidemiology comes to its limits and an enhanced risk – though biologically plausible – cannot be recognized even in very large populations. Since, however, no lower threshold can be recognized for stochastic effects, ICRP and the community of radiation protection in general assume a linear dose risk dependence without threshold and recommend as a conservative approach the so-called Linear-No-Threshold-Modell (LNT hypothesis).

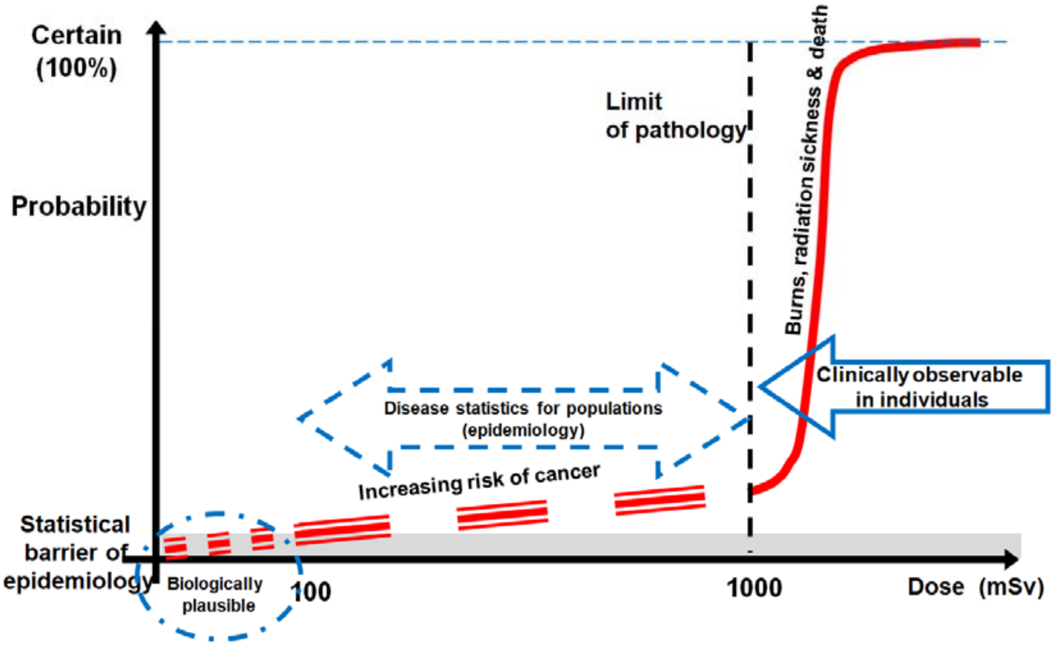

Fig. 1*: Probabilities of health effects due to ionizing radiation (UNEP 2016; modified)*

These observed and hypothetical health effects constitute the basis for the radiation protection of workers and of the public. The influence of the knowledge about radiation exposures and health effects onto the development of radiation protection is discussed below.

2.6 The ICRP recommendations

The goals of radiation protection are the avoidance of deterministic effects and the limitation of stochastic effects to a tolerable or acceptable level. To achieve these goals radiation protection is based on three fundamental principles that were formulated in ICRP 103 (ICRP 2007) as follows:

> *„The Commission continues to regard these principles as fundamental for the system of protection, and has now formulated a single set of principles that apply to planned, emergency, and existing exposure situations. In these Recommendations, the Commission also clarifies how the fundamental principles apply to radiation sources and to*

the individual, as well as how the source-related principles apply to all controllable situations."

The three fundamental principles read:

- *„**The principle of justification**: Any decision that alters the radiation exposure situation should do more good than harm."*
- ***The principle of optimization of protection**: the likelihood of incurring exposures, the number of people exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable, taking into account economic and societal factors."*
- ***The principle of application of dose limits**: The total dose to any individual from regulated sources in planned exposure situations other than medical exposure of patients should not exceed the appropriate limits recommended by the Commission."*

These principles shall be applied for the occupational exposure, the medical exposure, and the exposure of members of the public, as well as for the non-medical application of radiation for humans in all exposure situations, i.e. in planned, existing, and emergency exposure situations. For the latter two exposure situations reference dose values are stipulated instead of dose limits. The three fundamental principles of radiation protection have become the basis of international and national laws and regulations.

2.7 Safety from deterministic effects

The recommendations and regulations for radiation protection developed with time in line with the development of the knowledge about the health effects of ionizing radiation and have led to more and more safety by adjusting the dose limits.

The development with time of the dose limits for the occupational exposure and for the exposure of members of the public are shown in Fig. 2. Tables 1 and 2 give details of these developments on the basis of the recommendations of ICRP, the EURATOM basic safety standards, and the German Radiation Protection Ordinance. The Swiss regulations likewise followed this development.

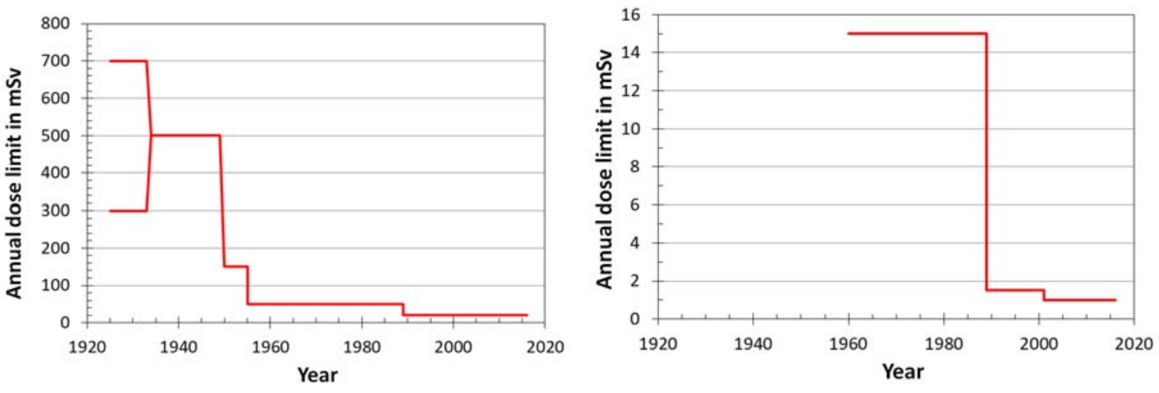

***Fig.2**: Development with time of limits for the occupational radiation exposure (left) and for the radiation exposure of the public (right). The initially two values for the occupational exposure reflect the uncertainty of dose definitions, which were the basis of the proposed limits for the erythema dose by* MUTSCHELLER *(1925) and* SIEVERT *(1925).*

It took up to the year 1925, to discuss the necessity to install a committee for radiation protection at the first *International Congress of Radiology* (ICR) in London which then led to the foundation of the *International Commission on Radiological Protection* (ICRP) during the second congress in Stockholm in the year 1928 (Clarke und Valentin 2009).

ICRP should stipulate the necessary standards of radiation protection based on the scientific knowledge. At the same time, it was clear that the harmful effects of ionizing radiation were a matter of dose. In addition, the healing value of ionizing radiation for the treatment of malign diseases depended on the applied dose. Therefore, the *International X-Ray Unit Committee*, later *International Committee for Radiological Units* (ICRU) (today named: The International Commission on Radiation Units and Measurements) was likewise founded at the second congress after discussions during the first congress in 1925 (http://www.icru.org/home/uncategorised/history). The first task of the ICRU was the definition of a unit for radiation measurement for medical applications.

It took another 16 years until ICRP published and considered a complete list of biological effects of radiation exposures (ICRP 1950):

> "*It appears that the effects to be considered are: (1) superficial injuries, (2) general effects on the body, particularly the blood and blood-forming organs, e.g., production of anemia and leukemia, (3) the induction of malignant tumors, (4) other deleterious effects including cataract, obesity, impaired fertility, and reduction of life span, (5) genetic effects.*"

Until 1956 radiation protection was exclusively aimed at the protection of occupationally exposed persons. Only in the year 1956, ICRP named the public as a target group of radiological protection (ICRP 1956). This was a consequence of the observation of harmful health effects among the survivors of the atomic bombing of Hiroshima and Nagasaki and of fears of cancer and genetic effects, which might be associated with the global fallout of the atmospheric nuclear weapons tests.

2.8 Safety by limitation of stochastic effects

In the publication 26, the ICRP formulated a complete concept of radiation protection in the year 1977 (ICRP 1977). Now, the ICRP distinguished stochastic and non-stochastic effects and suggested to extend radiation protection to workers and the public.

The ICRP recommended not only dose limits but also the fundamental principles of justification and the ALARA principle (*as Low As Reasonably Achievable considering social and economic factors*). The ICRP 26 also provided a general rationale for the dose limits:

> „*The aim of radiation protection should be to prevent detrimental non-stochastic effects and to limit the probability of stochastic effects to levels deemed to be acceptable*."

The particular problem regarding stochastic effects is that it is assumed for radiation protecion that the stochastic risk, such as the risks of solid cancers, leukemia, and genetic diseases, have no dose thresholds and the severity of the diseases does not depend on the doses, but that the number of affected people increases with dose. This immediately leads to the question: What is *„acceptable*“?

ICRP 26 followed the concept to compare the risks of radiation-induced stochastic effects with risks in so-called „safe“ occupations: *„comparing this risk with that for other occupations recognized as having high standards of safety“.* By this concept, the ICRP concluded in publication 26 after taking into account further assumptions that the risk associated with an equivalent dose of 50 mSv per year would be „acceptable“. This concept corresponded to the approaches in other occupations and was discussed in detail in the ICRP publications 27 and

45. It is to mention here that the term „acceptable“, as used in ICRP 26, corresponds to the term „tolerable“ in ICRP 103. This latter term will also be used here.

2.9 The recommendations of limits

It should be realized that ICRP 26 considered the experience that dose values of a large group of occupationally exposed persons can be described by a logarithmic normal distribution with an arithmetic mean of about 5 mSv per year. In Germany and Switzerland, this mean value is clearly lower than 5 mSv per year. Only for very few persons, the dose value lies near the present dose limit of 20 mSv per year.

Dose limits are primarily used for planning of technical installations or for the surveillance of individual persons. For further optimization of the protection, ICRP introduced so-called *Dose Constraint* (ICRP 1991, 2007). By a dose constraint which is lower than the dose limit an improvement of the radiation protection can be achieved by communication with the licensee in combination with an optimization process which takes into account all specific circumstances of the installation during planning.

ICRP 60 did not maintain the above-mentioned approach of comparing the radiological risks with those in other occupations. Rather, ICRP strived towards a definition of what is *unacceptable*, *tolerable* und *acceptable*. *Unacceptable* means under normal working conditions that a risk shall not be taken; this may be different in emergencies or catastrophes. Situations are *tolerable* if they are not desirable but can be tolerated if optimized, while *acceptable means* that the inferred risks can be taken without further optimization. ICRP 60 set the borderline between „*tolerable*“ and „*unacceptable*“ at a risk of one hypothetical radiation-induced death per year and per 1 000 persons. The explanatory statement read (ICRP 1991, Annex C, clause C14):

> *„A report of a Study Group of the British Royal Society (1983) concluded that imposing a continuing annual occupational probability of death of 1 in 100 would be unacceptable, while they found the situation less clear with regard to an annual probability of death of 1 in 1000. They felt that the latter probability level could „hardly be called totally unacceptable provided the individual at risk knew of the situation, judged he had some commensurable benefit as a result, and understood that everything reasonable had already been done to reduce the risk". However, the annual probability of death is only one of the attributes, which are appropriate to take into account. In the following, a number of other aspects will be considered.*“

Based on these considerations and on actual epidemiological data regarding the cancer risk at Hiroshima and Nagasaki as well as the adoption of a multiplicative dose-risk model ICRP set the dose limit for occupational exposed workers to 20 mSv per year, equivalent to 100 mSv per 5 years with the reservation that in no single year 50 mSv shall be exceeded.

Up to the 1950ties, radiation protection was a matter for medical professionals and to a lesser extent for scientists. The public was not affected by the respective activities – unless as patients. It was at the time of the atmospheric nuclear weapons tests and of the construction of nuclear facilities and nuclear power plants, which released radioactivity into the environment, that the question for the radiation exposure of the public became relevant. Only much later and triggered by the experience of the miners, natural radioactivity and radiation were perceived as potentially harmful and considered with respect to limiting the respective exposure

Around the year 1950, genetic defects were suspected in the offspring of the survivors of the atomic bombing of Hiroshima and Nagasaki. Respective fears, however, could not be substantiated. Up to now, genetic effects were only observed in animal experiments mainly with the fruit fly *Drosophila melanogaster*. However, increased incidence of leukemia and solid cancers was observed in the survivors themselves. These observations changed the radiation protection. It was no longer the main topic to prevent deterministic effects; in addition, the risk of stochastic effects should be reduced to a tolerable or better acceptable level.

With the atmospheric explosions of nuclear weapons during the Cold War and as a consequence of the worldwide contamination by radioactive fallout the focus of radiation protection was altered: Now the radiation exposure of the general public became an important topic.

In addition, the nuclear installations and reactors intended for military and peaceful use of nuclear energy released radionuclides into the environment via air and water. So the radiation exposure of members of the public became an subject of surveillance and a criterion for licensing of nuclear installations.

With the recommendation ICRP 103 (ICRP 2007), which became the basis for the revision of the EURATOM basic safety standards of 2013 (EC 2013), for the German Strahlenschutzgesetz von 2017 (BMUB 2017) and also for the legal regulations in Switzerland (SCHWEIZER BUNDESRAT 2017, BAG 2017), the system of radiation protection was extended. ICRP now distinguished planned, existing and emergency exposure situations for the occupationally exposed workers, the general public, patients and the environment. The new system is exemplified in Fig. 3. Dose limits apply only for planned exposure situations. In this case, the dose limit for the public of 1 mSv per year is maintained. Below this dose limit, ICRP recommends the application of d*ose constraints*.

For emergency exposure situations, which only last a limited time, ICRP recommends reference values in a bandwidth of 100 mSv per year to 20 mSv per year for the public. For existing or long-lasting exposure situations reference values with a bandwidth of 20 mSv per year to 1 mSv per year apply. Exceeding the upper reference level is considered as intolerable and requests protective actions. The goal in existing and emergency exposure situations is to bring the dose of the so-called representative person of the affected population below the respective lower reference value. For existing exposure situations, the final goal stipulated by (ICRP 2006) is to reduce the dose to less than 1 mSv per year for the representative person according to ICRP 101. The reference values refer to the additional dose and do not consider the natural radiation exposure at the respective site, which actually may much larger than 1 mSv per year.

Tab. 1*: Development with time of dose limits for the occupational exposure*

Year	Dose limits
1925	1. Int. Congress of Radiology in London MUTSCHELLER & SIEVERT propose a limit of 10% of the erythema dose. There is ambiguity about the measurement quantity dose. This means: ~70 R per year = 0.7 Sv per year (200 kV X-rays), ~30 R per year = 0.3 Sv per year (100 kV X-rays)
1928	2. Int. Congress of Radiology in Stockholm; foundation of the ICRP and the ICRU
1934	ICRP recommendation: 0.2 R per day, 1 R/w, 50 R per year ≅ 0.5 Sv per year
1950	ICRP recommendation: 3 mSv per week, 150 mSv per year
1956	ICRP recommendation:1 mSv per week, 50 mSv per year
1977	ICRP 26: comparison of radiological risk with that of occupational accidents; additive risk model, cost-benefit-approach 500 mSv per year for skin, hands and feet, 300 mSv per year for the lens of the eye because of deterministic effects 50 mSv per year for the occupational exposure; on average 5 mSv per year

Year	Dose limits
1990	ICRP 60: multiplicative model Effective dose 20 mSv per year, 150 mSv per year for the lens of the eye, 500 mSv for skin, hands and feet
2007	ICRP 103: reference values for existing and emergency exposure situations, limits for planned exposure situations Effective dose 20 mSv per year, 150 mSv per year for the lens of the eye, 500 mSv for skin, hands and feet
2013	Directive 2013/59/EURATOM: Effective dose 20 mSv per year, 20 mSv per year for the lens of the eye, 500 mSv for skin, hands and feet
2017	Radiation protection law (StrlSchG) in Germany Effective dose 20 mSv per year, 20 mSv per year for the lens of the eye, 500 mSv per year for skin, hands and feet

The representative person (ICRP 2006) replaces the earlier used critical group and shall represent the 95th percentile in probabilistic assessments of the radiation exposure. The representative person is a normal person (male or female) with average lifestyle and nutritional habits, which can also be looked at as a „*more exposed person*". A discussion of the role of the representative person was given in SSK (2013).

In planned exposure situations, optimization shall be made below the dose limit considering social and economic aspects. A lower limit of optimization, however, is not recommended.

Tab. 2*: Development with time of dose limits for the public*

Year	Dose limits
1958	ICRP Genetically significant does 5 mSv per year
1959	EURATOM basic safety standards 5 rem = 50 mSv accumulated up the age of 30 years (entire population) 0.5 rem per year = 5 mSv (particular groups oft he population)
1960	1st radiation protection ordinance (StrlSchV) in Germany §29 1.5 rem per year = 15 mSv per year person occasionally in controlled areas §29 0.5 rem per year = 5 mSv per year person in controlled areas
1977	ICRP 26 (§119) Equivalent dose 5 mSv per year for the critical group. It is felt „*prudent*" to stay below 1 mSv per year in case of life-long exposure. It is assumed that the actual doses will be lower by a factor of ten.
1989	Radiation protection ordinance (StrlSchV) in Germany §44 (1) 1,5 mSv per year due to direct radiation §44 (2) 5 mSv per year after exceptional permission by the authorities §45 „30 mrem per year concept", i.e. je 0,3 mSv per year due to releases of radioactivity
1990	ICRP 60 1 mSv per year, 15 mSv per year for the lens of the eye, 50 mSv per year for the skin
Switzerland: since1994	A first radiation protection ordinance entered into force in Switzerland in the year 1963 as ordinance in connection with the Atomic Law regarding the Peaceful Use of atomic Energy as of December 23, 1959. This ordinance was revised in the years 1976 and 1994. With the version 1994 gilt Also in Switzerland a dose limit for the public of 1 mSv per year applies for man-made sources of radiation. Today's radiation protection ordinance (StSV 814.501) as of April 22, 2017 came into force January 1, 2018. The basis

Year	Dose limits
	is the Radiation Protection Law (StSG 814.50) as of March 22, 1991, status as of May1, 2017.
2001	Radiation protection ordinance (StrlSchV) 1 mSv per year (15 mSv per year for the lens of the eye) 0.3 mSv per year each due to releases by air and water A few 10 µSv per year are used as a criterion for releases from the atomic law 1 mSv per year as a reference value for elevated radiation exposures from residues with natural radioactivity and from natural radiation
2007	ICRP 103 1 mSv per year, 15 mSv per year for the lens of the eye, 50 mSv per year for the skin
2013	Directive 2013/59/EURATOM 1 mSv per year, 15 mSv per year for the lens of the eye, 50 mSv per year for the skin
2017	Radiation protection law (StrlSchG) 1 mSv per year from the sum of licensed activities, 15 mSv per year for the lens of the eye 0.3 mSv per year each due to releases by air and water from nuclear installations (a few) 10 µSv per year as a criterion for release from the atomic law 1 mSv per year as a criterion for the release of residues with natural radioactivity 1 mSv per year reference value for legacies 1 mSv per year reference value for radioactivity in building materials 300 Bq/m^3 reference value for Radon in homes ≅ 10 mSv per year effective dose

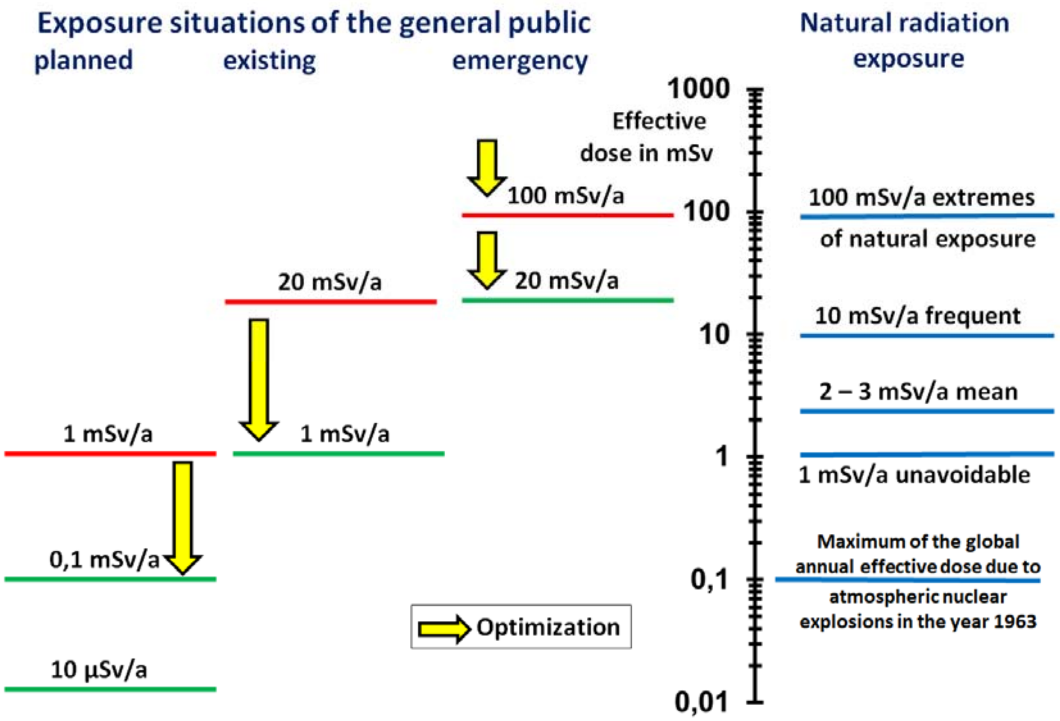

***Fig. 3**: The system of limits, dose constraints, and reference values and the optimization of protection according to ICRP 103 (ICRP 2007). It is compared to the bandwidth of the natural radiation exposure. For planned exposure situations, a dose limit (red) of 1 mSv per year holds. The lower limit of optimization (de minimis) of 0,1 mSv per year, proposed here, is given for planned exposure situations in green as well as the present clearance value of 10 µSv per year. For existing and emergency exposure situations, the upper reference values are given in red, the lower ones in green. According to ICRP 103 a reference value of 1 mSv per year is aimed at in existing exposure situations as a long term goal of optimization.*

2.10 Radiation protection has achieved safety: a success story

The system of radiation protection is mainly based on the recommendations of the ICRP, the international basic safety standards, and national regulations. The fundamental principles of justification, optimization and dose limitation provide a solid basis for reasonable and efficient protection.

The increasingly equal treatment of natural and man-made radioactivity and radiation in the regulations provides an important step towards a holistic consideration of radiation exposures and their associated risks of stochastic health effects. The reality of radiation exposures has achieved the highest possible safety for workers and the general public.

Safety is usually a feeling; it is relative and depends on the context.

In radiation protection safety and minimization of risk refers to the avoidance of deterministic effects and to the minimization of stochastic health effects considering social and economic factors. The system of radiation protection works in all three exposure situations: planned, existing, and emergency exposure situations for workers, the public, and patients. The strong decrease of the occupational exposures due to continuing and consequent optimization since the 1990ties is a success story of radiation protection; see e.g. (BfS 2014; ENSI 2013; UNSCEAR 2008).

The additional radiation exposure of the public in the vicinities of nuclear installations and power plants is quantified in the annual reports to the German Parliament as less than 0.01 mSv per year. This value is calculated extremely conservative. The actual exposures of the most highly exposed persons due to the releases of radioactivity and direct radiation is lower by at least a factor of 10, probably even a factor of 100 (VÖLKLE 1984 und 2009, SSK 2008). For the majority of the German population it is close to zero.

The numbers published in Switzerland are calculated by ENSI based on the actual releases and annually published (ENSI, 2016). The highest values with 0.0043 mSv in the year 2016 for a one-year-old child are about the same as in Germany. Also these dose values are calculated on the basis of extremely conservative assumptions; realistic dose estimates are about a factor of 50 lower (VÖLKLE, 1984). Such a realistic dose assessment, which was demanded by among others by the SSK (SSK 2013), never was performed in Germany. Our societies miss a culture of a realistic assessment of radiation exposures of the public and of putting them into the context of natural radiation exposures and other risks.

In spite of all the successes of radiation protection, radiation accidents and intolerably high radiation exposures can and will not be totally avoided in the future. To prevent them as far as possible or to minimize their consequences in the case of their occurrence remains a continuous and permanent task of radiation protection.

2.11 Good radiation protection continues to be a pre-eminent necessity

Without the development of radiation protection since 1925 there would be intolerably high exposures because without it we would neither know the radiation exposures nor which doses are acceptable or tolerable. Radiation protection is necessary in order to avoid accidents and to guarantee optimal safety. Knowledge is the basis for judging about the necessity of protective measures and about the feasibility and options of optimization so that work activities are planned and performed with the goal of keeping the additional doses tolerable. Experienced and competent professional of radiation protection are needed even though health effects are to be expected only at relatively high doses.

Radiation protection is necessary to avoid accidents and intolerable doses and to achieve best possible safety.

Today the question has to be asked which further improvements are needed and reasonable beyond the well-founded and successful system of radiation protection as laid down in ICRP 103. For radiation protection, there is always the conflict between scientific knowledge and societal perception of radiation protection. Therefore, it must not stay in an ivory tower. It has continuously to answer question how can put into practice what appears scientifically and theoretically reasonable.

Radiation protection needs a solid theoretical superstructure with ethical foundation (IRPA 2004) and code of conduct (IRPA 2011) which assures its independence. Radiation protection can only be credible if it is free of influences of politics or of groups which act for their own particular interests and thereby again and again try to misuse radiation protection for their purposes. Only independent professionals can be perceived and accepted by society as credible and reliable partners.

Radiation protection needs competence in a variety of scientific professions and seriousness accompanied with openness for new findings. It needs continuity in the regulations, but also discussion and readiness for further development. The latter can only be achieved by permanent education, self-education, and promotion of young people in this field. Finally, radiation protection should develop into a culture of radiation protection of practitioners and the society as a whole; see (MICHEL 2009, IRPA 2014). A culture of radiation protection should become a part of a general safety culture.

3. The natural radiation and its associated risk – a benchmark for radiation protection

3.1 Introduction

Natural radioactivity and radiation are unavoidable phenomena of the human environment. They set a natural lower limit to the efforts of radiation protection for reducing radiation exposures and their associated risks. The remaining risks match those of normal conduct of life of people living in modern societies with highly developed technologies and medical care. A further reduction of man-made exposures which does not change the total exposure anymore cannot be justified from the viewpoint of radiation protection. In contrast, such a reduction leads to a waste of resources which otherwise could be better used for the benefit of humans and their environment.

3.2 The natural radiation exposure

Natural radioactivity and radiation are omnipresent; see for instance MICHEL et al. (2006), UNEP (2016). They cause a natural radiation exposure from which no human can escape. For a keynote presentation on „Naturally radioactive materials – need and use them“ see the German-Swiss StrahlenschutzPraxis (SSP) issue 1/2017 and on “Surveillance of incorporation of natural radioactivity” in SSP issue 2/2017.

The reality of the natural radiation exposure in Germany is shown in (Tab. 3). On average it amounts to 2.1 mSv per year (BMUB 2015), of which 0.7 mSv per year is external exposure due to cosmic and terrestrial radiation, 0.3 mSv per year due to ingestion of radionuclides with food and drink, and 1.1 mSv per year due to inhalation of radionuclides, mainly Radon and its progeny. These are mean values of the natural radiation exposure which, however, is highly variable. For Switzerland, the Bundesamt für Gesundheit published the following average dose values for the Swiss population from natural radioactivity and radiation in 2016 (BAG 2016): terrestrial radiation 0.35 mSv per year, cosmic radiation 0.4 mSv per year, radionuclides in the human body 0.35 mSv per year, inhalation of Radon and Radon progeny in homes 3.2 mSv per year, in total consequently 4.3 mSv per year. When comparing the inhalation doses in Germany and Switzerland, it has to be taken into account that different dose conversion coefficients for Radon are used in the two countries.

The doses due to inhalation in Germany could about double if the new dosimetric approach of ICRP for Radon in homes would be used; see the detailed discussion in chapter 4.5.9. It has to be emphasized that 1 mSv effective dose due to Radon and Radon progeny according to the up to now dosimetry is equivalent to an equivalent dose to the lung of 10 mSv.

The variability of the natural radiation exposure can be quantified by Monte-Carlo-methods based on the distributions of measured values of the environmental radioactivity and radiation. Vahlbruch calculated a 95% coverage interval for the natural radiation exposure of people in Lower Saxony/Germany of 1.2 mSv to 4.7 mSv (VAHLBRUCH 2004). The individual components of the natural radiation exposure had 95% coverage intervals of 0.48 mSv per year to 0.97 mSv per year for the external exposure, of 0.22 mSv per year to 0.40 mSv per year due to ingestion, and of 0.3 mSv per year to 3.7 mSv per year for inhalation.

Fig. 4 shows the probability density function of the natural radiation exposure and its components in Lower Saxony/Germany. Tab. 4 extends these data for entire Germany. Summarizing it can be stated that a natural radiation exposure of about 1 mSv per year to 1.5 mSv per year represents an unavoidable lower limit for the German population. This natural exposure is given by nature and unavoidable all over the world!

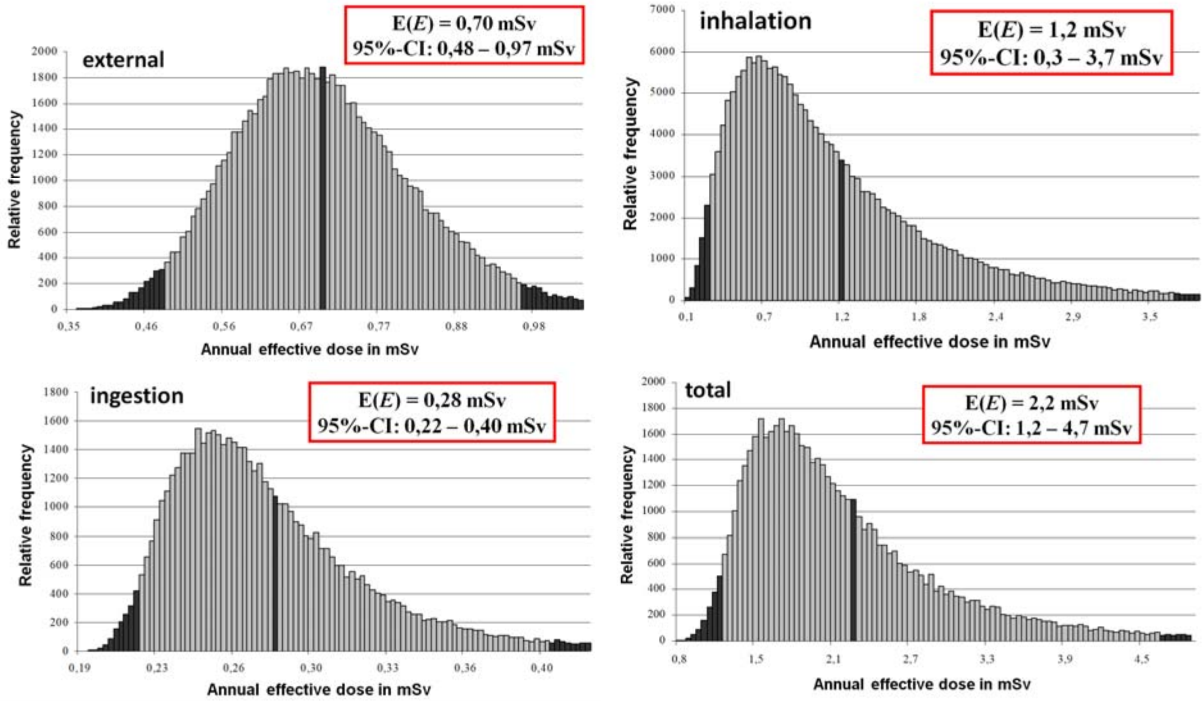

***Fig. 4**: Distribution densities of the age-averaged effective annual doses (E) due to external exposure (top left), inhalation (top right) and ingestion (bottom left) as well as the total natural radiation exposure (bottom right) in Lower Saxony/Germany. In addition, the expectations* E(*E*) *and the 95%-coverage intervals (95%-CI) of the effective doses are given. (MICHEL et al. 2006, VAHLBRUCH 2004).*

The natural radiation exposure in Germany and Switzerland are in the rather low midfield of the worldwide natural radiation exposures and does not show extraordinary anomalies, even if in granite mountains at elevated heights the terrestrial and cosmic radiation is somewhat higher. Countries with higher natural radiation exposures on the average and on the extremes are Norway, Sweden and Finland. For Finland, the probability density function of the natural radiation exposure of the population is given in Fig. 5. In addition, Fig. 5 gives a survey of the portion of some European countries the natural radiation exposure of which exceeds 10 mSv effective dose per year. A detailed discussion of the anomalies of the natural radiation exposures was given elsewhere (Michel et al. 2006).

Tab. 3: *Expectations (mean values) and in parentheses 95% coverage intervals of the effective natural annual effective does in mSv in Germany (*Michel *et al. 2006,* Vahlbruch *2004)*

Age class	≤ 1 year	> 1– ≤ 2 years	> 2 – ≤ 7 years	> 7 – ≤12 years	> 12 – ≤ 17 years	> 17 years
External	0.7 (0.5 – 1.0)	0.7 (0.5 – 1.0)	0.7 (0.5 – 1.0)	0.7 (0.5 – 1.0)	0.7 (0.5 – 1.0)	0.7 (0.5 – 1.0)
Inhalation	0.2 (0.0 – 0.5)	0,3 (0.1 – 1.0)	0.6 (0.1 – 1.6)	1,.0 (0.2 – 2.9)	1.3 (0.3 – 3.8)	1.4 (0.3 – 4.1)
Ingestion	0.8 (0.5 – 1.6)	0.4 (0.3 – 0,.9)	0.4 (0.3 – 0.7)	0.4 (0.3 – 0.6)	0.4 (0.3 – 0.7)	0.2 (0.2 – 0.3)
Total	1.8 (1.2 – 2.6)	1.5 (1.0 – 2.3)	1.6 (1.1 – 2.7)	2.1 (1.2 – 3.9)	2,.4 (1.3 – 4.8)	2.4 (1.2 – 5.1)

A particularity of the natural radiation exposure has to be mentioned. Aside of the variability of the external exposure and of the exposure due to inhalation, also the exposure due to ingestion of radionuclides is highly variable worldwide. Regular consumption of fish, crustaceans, and shellfish can contribute significantly to the internal exposure because of the partially high concentrations of natural ^{210}Po and ^{210}Pb. Internal doses up to 3 mSv per year were reported (IAEA 1998, Nord-Cotentin Radioecology Group 1999).

The natural radiation exposure is multifactorial. It is helpful to realize what might cause an additional effective dose of about 0.1 mSv per year. According to Michel (2016) and Chen et al. (2015) it is:

- travelling to Hawaii or Tokyo (cosmic radiation),
- living one year at Goslar close to the Harz Mountains in Germany instead of at Hannover/Germany (terrestrial radiation),
- consumption of two Brazil nuts per day (^{226}Ra),
- consumption of one lobster or of 150 g fish per month (^{210}Pb, ^{210}Po),
- consumption of two kg of mushrooms from areas in Bavaria/Germany which were highly contaminated by fallout from Chernobyl with 4 000 Bq/kg ^{137}Cs,
- staying 10 minutes in a underground Radon tunnel (Bad Gastein/Austria) with a ^{222}Rn concentration of 150 000 Bq/m^3 (according to the up to now dose convention).

An effective dose of 0.1 mSv per year disappears completely in the random variability of the natural radiation exposure. Therefore, the German Commission on Radiological Protection (www.ssk.de) recommended in the year 2015 to adopt 0.1 mSv per year as a reasonable and practicable lower cut-off value for the implementation of the surveillance of the dose limit of members of the public for the sum of exposures from licensed work activities (SSK 2015).

Tab. 4*: Statistical parameters of the total age-averaged natural effective annual doses in mSv in Germany and selected federal states of Germany. (Up to now, there are no such calculations in Switzerland). The age-averaged total annual dose is calculated according to a convention by UNSCEAR by the formula* $E_{\text{gesamt, Mittel}} = 0{,}05 \times E_{\text{gesamt},1<a\le 2} + 0{,}30 \times E_{\text{gesamt},7<a\le 12} + 0{,}65 \times E_{\text{gesamt},\, a>17}$.

	Age-averaged mean	Typical range	
World UNSCEAR (2000)	2,4	1,0	10
Germany BfS (2005)	2,1	-	-
	Expectation	2,5%-percentile	97,5%-percentile
Germany	2,2	1,2	4,6
Lower Saxony	2,2	1,2	4,7
Saxony	2,6	1,2	6,3
Rhineland-Palatinate	2,8	1,2	6,2

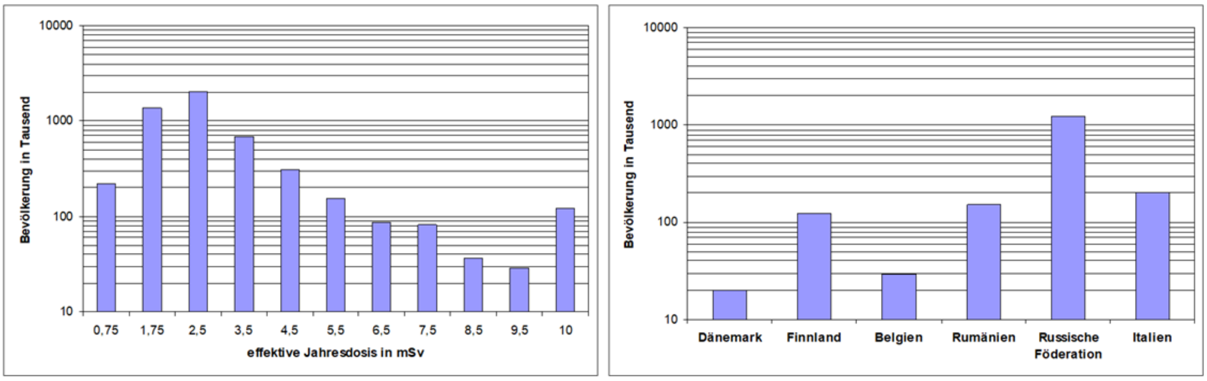

Fig. 5*: Distribution of the natural radiation exposure in Finland (left) and populations with more than 10 mSv per year of natural radiation exposure (data from UNSCEAR 2000).*

A dose rate of 0.01 mSv per year is frequently used in radiation protection in connection with the clearance of man-made radioactive materials. Let us realize what makes an effective dose of 0.01 mSv per year. It is respectively:

- a flight back and forth from Germany to Mallorca (cosmic radiation),
- a day on the summit of Germany's highest mountain, the Zugspitze, or at the Jungfraujoch in Switzerland (cosmic radiation),
- one month at Goslar near the Harz Mountains in Germany instead of Hannover/Germany (terrestrial radiation),
- consumption of one lobster per year or one meal with 150 g of fish (^{210}Pb, ^{210}Po),
- consumption of two Brazil nuts per month (^{226}Ra),
- consumption of 200 g mushrooms from the highly contaminated regions in Bavar-

ia/Germany with 4 000 Bq/kg ^{137}Cs,
- one day in a home with 110 Bq/m^3 ^{222}Rn.

These data demonstrate that 0.01 mSv per year is an insignificant contribution to the radiation exposure. To think of protective measures at such low dose values would be an excess of precaution. By the way, it would only be feasible for man-made radionuclides. One must not necessarily object the clearance criterion of some 0.01 mSv per year for the most exposed persons. For man-made radionuclides it is possible by calculations; but it is neither reasonable nor acceptable in many areas of life.

The German regulations, therefore, apply a realistic reference value of 1 mSv per year for natural radioactive materials in acknowledgement of the absurdity of lower values. For the estimation of radiation exposures due to natural radioactivity and radiation 0.1 mSv per year is a realistic limit of recognition and detectability.

In this context, also the medical diagnostic radiation exposure – without the therapeutic applications of ionizing radiation – has to be mentioned. According to the German Report to the Parliament (BMUB 2017) the medical diagnostic exposure – averaged over the entire population and including those persons which not underwent diagnostic exposure – amounted to 1.8 mSv per year in the year 2014. The respective value in Switzerland was 1.2 mSv per year according to the Bundesamt für Gesundheit (BAG 2015). The individual doses per examination are between 0,1 mSv and 20 mSv. Assuming that medical practitioners take the justifying indication honestly, the medical diagnostic exposure is not dealt with here further. It can be avoided by refusing radiological and nuclear medicine examinations; but the inferred health risk may be much larger than the radiological risk. It has, however, to be pointed out that the medical diagnostic radiation exposure has to be taken into account in a holistic assessment of the radiation risk of a person or a population – notwithstanding the justifying indication.

**What cannot recognized as a deviation from normality,
has to be considered as normal.**

3.3 The risks of daily life

What is the relevance of the natural radiation exposure for the assessment of risks and safety? The radiological risk and the achievable safety are downwards limited by the natural radiation exposure – at least that part of it which is unavoidable. Therefore, the question has to be answered: How safe respectively how risky is our natural environment?

The real risks of life are well known. Everybody will die from various causes earlier or later. Every year about 1.1 % of the 80.8 millions of people in Germany die (Tab. 5 and Figs. 6 to 8). The most frequent causes of death are coronary and heart diseases and cancers. Leukemia is a rarer disease. Leukemia shows a large geographical variability and has large number of possible causes; ionizing radiation is just one of the relevant factors. The releases of radioactivity by nuclear power plants in normal operation do not cause an elevated leukemia risk for people living in the vicinity of the plants – in particular not for the respective children (SSK 2008, SCHÄDELIN et al. 2017).

More frequent than leukemia are deadly accidents of all causes. The probability of accidents at work and consequently the respective death rates differ widely for the different professions and shall not be further discussed here. Accidents at home and during leisure time – where we usually feel safe – are more frequent than traffic accidents though the safety of traffic is individually rated quite different. In addition, death due to homicide is much rarer than death due to accidents at home or during leisure time. From the case numbers of Table 5 an integral population risk can be calculated, i.e. the portion of the population suffering the respective deaths in a year. The integral population risk (the proportion of the population of a country which dies at age X due to a cause Y) is at the same time the death risk of the entire population; it strongly depends on the age of the individuals in the case of diseases.

***Tab. 5**: Integral population death risks in Germany in the year 2013 according to data of the German Statistical Federal Agency.*

Mortality	Deaths	Integral population risk per year
Total deaths	891 825	1.1E-02
Deaths due to heart and circulative diseases	354 493	4.4E-03
Cancer deaths	223 842	2.8E-03
Deaths due to all accidents	21 930	2.7E-04
Death due to home and leisure accidents	9 214	1.1E-04
Deaths due to housekeeping	8 675	1.1E-04
Deaths due to leukemia (2011)	7 618	1.0E-04
Deaths due to traffic accidents	3 542	4.4E-05
Deaths due to homicide	2 122	2.6E-05
Death due to accidents at work	932	1.2E-05

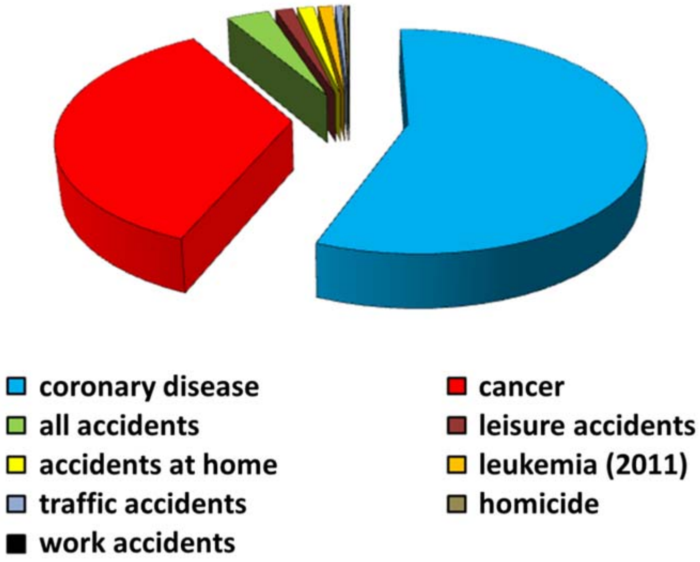

***Fig. 6**: Integral population death risks in in Germany in the year 2013*

The integral population risks are not easily to understand and difficult to interpret. For non-specialists they are to abstract and irrelevant because the individual is usually just interested in its individual risk; i.e. the probability to die at a certain age X due to a cause Y.

The individual risks of life (Fig. 8) are determined by the individual behavior, the behavior of our fellow men, the individual habits of life and consumption, the choice of profession and leisure time activities, nature and environment, genetics, proteomics, and, finally, by chance. Humans cannot influence genetics and chance; the other factors are controllable to varying degrees. While the environment depends largely on our fellow men, the personal behavior plays a more important role with respect to the other factors. According to Renn (RENN 2014 p. 132) about 2/3 of the total individual risk is determined by the own individual behavior by which one exposes oneself and others to certain risks.

Since nature itself constitutes by far the largest threats to humans, the largest efforts are undertaken to reduce their risk; emergency preparedness and defense and improvement of resilience, i.e. the capability to return as quickly as possible to normality. In medicine, preventive measures are developed and diagnoses and therapies are improved.

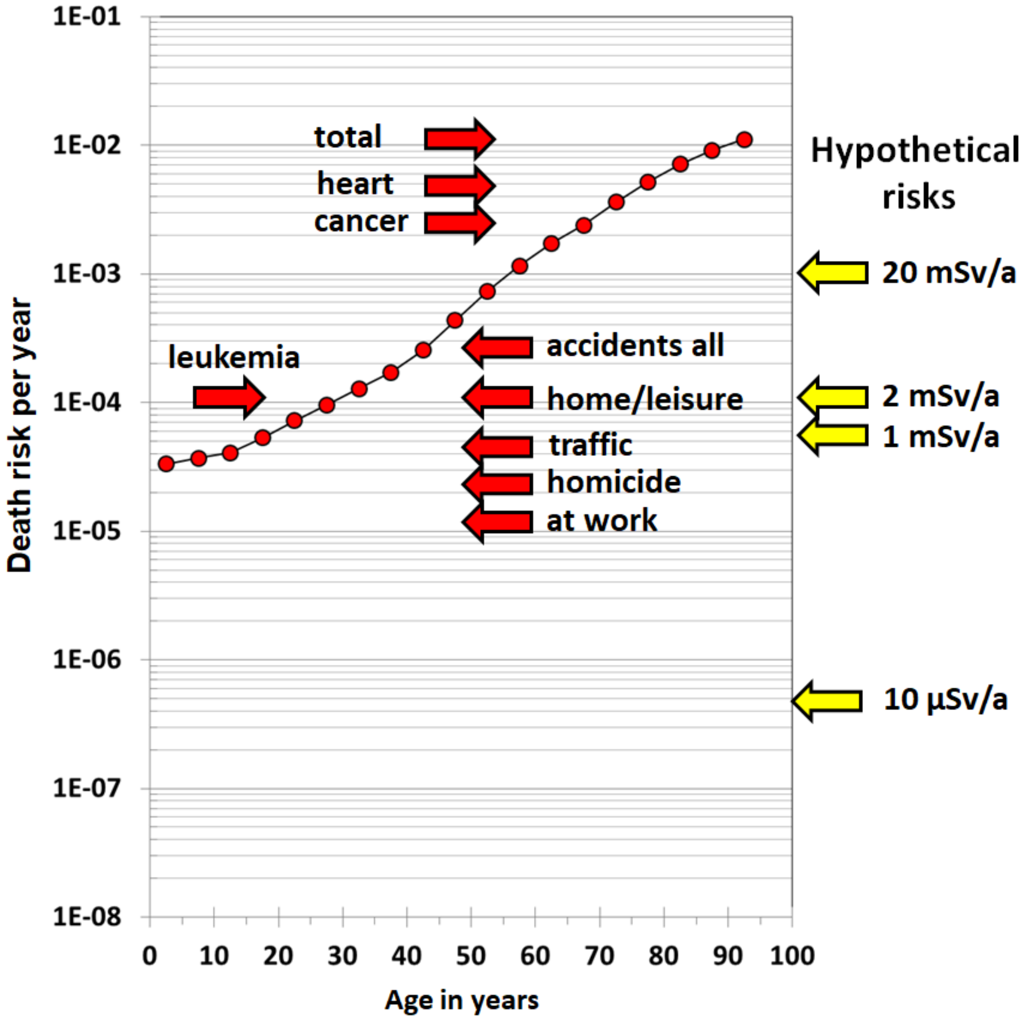

***Fig.7**: Distribution function of the population death risk in Germany in the year 2013. A breakdown of the causes of death is given (red arrows) in comparison with the hypothetical risks due to lifelong radiation exposures with the indicated effective doses per year (yellow arrows).*

An individual person is mainly interested in the individual death risk; i.e. the probability to die at a certain age. Respective data for Germany are given in Fig. 9. The total individual death risk decreases during the first years after birth to a minimum of 1 × 10^{-4} per year and then increases nearly exponentially with age. At an age of 60 to 70 years the death risk reaches 1 × 10^{-2} and at an age of 85 years it is about 0.1. It is also interesting to look for the age dependence of the risk due to accidents.

The risk of accidental risk in traffic increases with age and reaches a local maximum at an age of about 20 years. Then it remains practicably constant for some decades to increase again in the old age. Therefore, one should reframe from driving a car at old age and consequently use pedestrian crossings. Deadly accidents in homes have a completely different time-dependence. Their risks decrease with age during the first years of life and increase nearly exponentially at old age.

The individual death risks given in Fig. 9 are also average values; they depend on the place where the individual person lives, on the type of person, and on age. While in younger years traffic and other accidents dominate the risk until at moderate or old age accidents at home, cancer, coronary, and heart diseases take over. The individual has considerable influence on his own risk, e.g. by the behavior at home and in traffic, by life and consumption habits, by profession and leisure time activities. Risk factors which can be influenced by behavior are smoking, consumption of alcoholic beverages and drugs, obesity, nutrition and lifestyle. Since cancer, coronary, and heart diseases dominate at older age, preventive diagnostics (breast, prostate, colon, blood pressure, cholesterol, etc.) in combination with changes of lifestyle and in-time medical treatment can influence the death risk.

Personal risk optimization pays and means to be aware of the respective risks and to start with the largest risks. Compared to the risks of daily life the risks inferred by small doses of ionizing radiation of less than 1 mSv – or even 1µSv – are insignificant. For such low doses, measures of reduction of dose or risk as measures of optimization are no justified based on the ALARA principle because of the mismatch between efforts and benefit. They do not have any discernable influence on the total death risk.

3.4 Risks due to the natural radiation exposure

The radiological risks are dealt with next (Tab. 6). They are denoted here as hypothetical risks since one does not know whether they exist at all. They are exclusively based on the assumption of the validity of the *Linear No Threshold Hypothesis* **(LNT-hypothesis)** by which the risks of health effects observed at high doses are straight forward extrapolated to low doses in a linear way. A dose and dose rate effectiveness factor (DDREF) is applied for which ICRP recommends a value of two.

***Tab. 6**: Integral hypothetical population death risks due to radiation exposures in Germany for the reference year 2013.*

Radiation exposure	Population risk per year
20 mSv per year	1.0E-03
5 mSv per year	2.5E-04
Rn (D): 2 mSv per year[3]	1.0E-04
1 mSv per year	5.0E-05
10 µSv per year	5.0E-07

According to these assumptions, the hypothetical population risk caused by a radiation exposure of 2 mSv per year is numerical equal to the population risk of death by accidents at home and during leisure time. The risk associated with 1 mSv per year is equivalent to the death risk due to traffic accidents. A radiation exposure of 10 µSv per year is lower than the lowest accident risk. It is to emphasize that the non-radiological risks are based on numbers of real death cases for which the cause of death is evident. The real problem of the radiological risks is that up to now no marker has been discovered which would allow to distinguish radiation-induced cancers from those of other causes.

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2 Exposure according to the new ICRP dose conversion coefficients.

The following example may serve for clarification: A Radon exposure of 1.1 mSv per year (for Switzerland 3.2 mSv per year; by applying the dose conversion factor of the Statement on Radon by ICRP from the year 2009) increases the lung cancer risk by 2.2 percent (for Switzerland by 9.2 percent). The average annual occupational exposure of a worker in a Swiss nuclear power plant is 0.68 mSv, which is equivalent to an additional risk to die from cancer of 2.8×10^{-5} per year. The total risk to die from cancer thus is increased by 1.3 percent.

The hypothetical risk to die from cancer is increased by 4 percent due to an average radiation exposure of 2 mSv per year for aircraft personal compared to that of the normal population. Persons living in vicinity of a nuclear power plant who receive an hypothetical annual effective dose of 5 µSv per year from releases of radioactivity and direct radiation would have a risk to die from cancer which is increased by 0,01 percent compared to the spontaneous risk

For the comparison of the hypothetical radiological risks with other risks, just age-averaged individual risks are available (table 6). The individual risk of the mean natural radiation exposure of 2 mSv per year is 1×10^{-4} per year and thereby is equal to the minimal death risk a human faces throughout his life. Single exposures by 20 mSv respectively 1 mSv are associated with hypothetical risks of 1.3×10^{-5} and 6.3×10^{-7}. An extremely low additional radiation exposure of 10 µSv per year yields a calculated risk of 5×10^{-7} per year. However, every human is naturally exposed ot at least 1 mSv per year. 1 mSv was obtained already until birth and the exposure accumulates over the entire lifetime. On average, the exposure is higher than this by a factor of two and for many people higher by a factor of ten due to the variability of the natural radiation exposure.

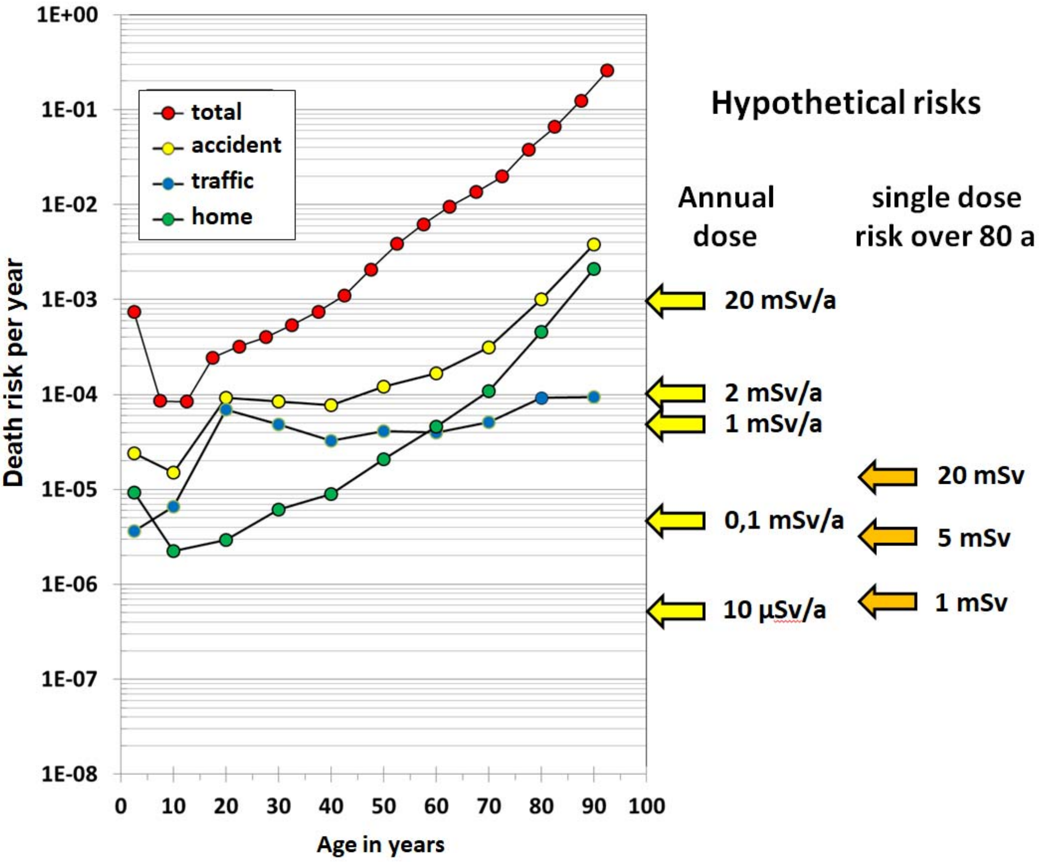


***Fig. 8**: Age-dependent individual death risks in Germany in the year 2013 with a breakdown according to the causes of death in comparison to the hypothetical risks due to lifelong exposures with the indicated annual doses (yellow arrows) and due to a single additional radiation exposure (orange arrows) assuming a distribution of the risk over 80 years).*

Tab. 7*: Age-averaged hypothetical individual death risks due to radiation exposure in Germany based on a risk coefficient of 5% Sv^{-1}. A mean life expectancy of 80 years was assumed.*

Effective dose	Age-averaged individual death risk
2 mSv per year	1.0E-04 per year
20 mSv	1.3E-05
5 mSv	3.1E-06
1 mSv	6.3E-07
10 µSv per year	5.0E-07 per year

The largest risks are the natural ones!

Our largest risks are natural ones or are caused by our normal living conditions: for examples diseases and epidemics, extreme weather conditions, earthquakes, flooding, tsunamis, crop failure and famines and so on. For such cases, large efforts for protection are justifiably undertaken as for instance costly medical care covering diagnostics and therapies as well as measures for hazard prevention and mitigation. But also safety standards, behaviour rules, and laws shall improve safety. Therefore, nature is only of limited use as a benchmark for safety.

Humankind must, however, life with the hypothetical risk of the natural radiation exposure. Potential effects of an additional exposure which are small compared to the natural exposure are not discernible and can only be estimated by calculations. Such effects are hypothetical and negligible compared to those of the natural exposure. Given the large variability of the natural exposure – which usually is not taken into account as a criterion for choosing a place to live or for the lifestyle – any exposure which is small compared to the bandwidth of the normal radiation exposure is not relevant.

If one takes into account the total dose a human is exposed to one comes to the conclusion that the lowest achievable risk defined by the natural radiation exposure. This is exemplified in Fig. 9. In this figure, the case of a 1-year-old child is chosen, which received the lowest possible effective dose of 1 mSv in the first year of life due to the natural radiation. The exposure of the child in the womb during pregnancy as well as the exposure due to Radon and its progeny in the first year are neglected here. One sees easily that an additional dose below 0.1 mSv does not discernibly change the total risk.

This is in essence the justification for

- the present limit of 1 mSv per year for additional radiation exposures of members of the public from the sum of all licensed practices according to the StrlSchG (BMUB 2017),
- the reference value of 1 mSv per year for the assessment of radiation exposures from legacies,
- the reference value of 1 mSv per year due to residues from NORM industries which need monitoring (BMUB 2017),
- the lower reference value as a long-term goal of optimization in existing exposure situations according to ICRP 103. The value of 1 mSv per year provides a reasonable lower limit for further optimizing measures of radiation protection for the public and the workers.

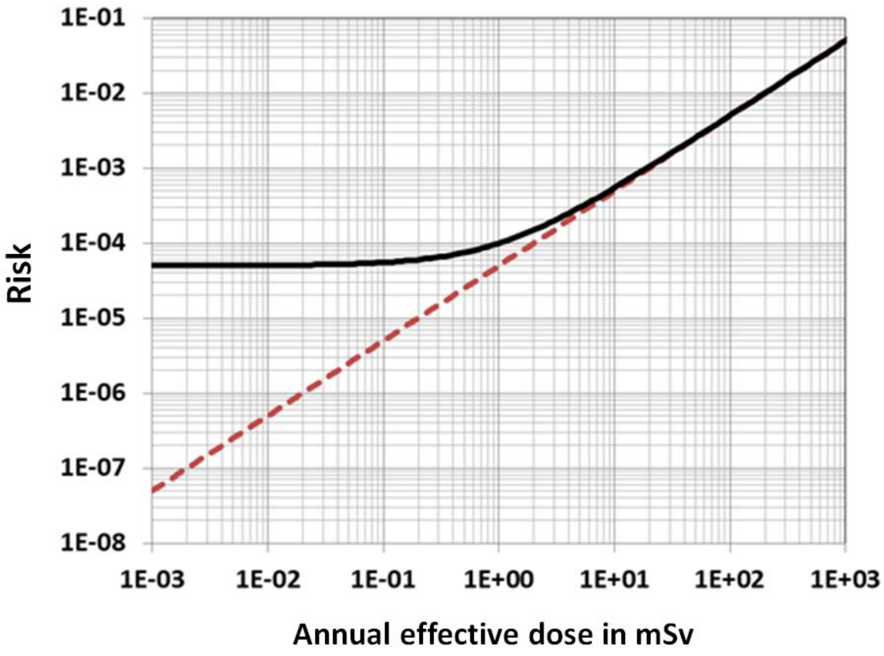


Fig. 9*: Total risk of stochastic detriment as function of an additional to a 1-year-old child, which exposed to a natural annual radiation exposure of at least 1 mSv (full line). The red broken line represents exclusively the risk due to the additional dose. An ICRP risk coefficient of 5% Sv^{-1} for the public was assumed.*

3.5 Conclusions

Responsible and rational radiation protection confines itself to the feasible, as long as it is meaningful and justified, and does not waste resources, which could be better used elsewhere for the benefit of humans and the environment. The endeavors for sustainability and the precautionary principle should likewise have the result of limiting the consequences of planned human activities onto the environment as low as feasible according to the state of science and technology in the spirit of ALARA.

4. The discomfort of the practitioners of radiation protection: recommendations for the future

4.1 Introduction

With this position paper, the German-Swiss Association for Radiation Protection (Fachverband für Strahlenschutz – FS) answers to the manifolds concerns which have been expressed regarding the actual status of radiation protection and presents theses as well as recommendations and their justifications for the future development. The FS presents this position paper for national and international discussion.

4.2 The widespread discomfort regarding radiation protection

During recent years, discomfort about the actual status of radiation protection has been expressed in a number of publications, including some by well-known experts such as ABEL GONZALES and ROGER COATES. They recommended (GONZALES et al. 2013, COATES 2014) to improve information and explanations in the following areas:

- *risk factors for radiation-induced health effects,*

- *goals, potential and limitations of epidemiological studies,*
- *quantities and units of radiation protection (a permanent task),*
- *risks due to internal exposure in comparison to that of external exposure.*

Note: By experience, it is well known that quite a number of terms related to ionizing radiation are frequently misunderstood and misused. This is glaring in the German-speaking areas where terms like *verstrahlt, verseucht, bestrahlt* are mingled and people do not distinguish between external irradiation, contamination and internal exposure. It is also a frequent misunderstanding that an external radiation exposure usually does not make the irradiated tissue radioactive (no activation).

The questions which were directed ROGER COATES and RENATE CZARWINSKI on behalf of the IRPA Executive Council to the associated societies (CZARWINSKI und COATES 2016, COATES und CZARWINSKI 2018) were answered by the FS earlier. They were presented at Annual Meeting of the FS at Usedom/Germany in the year 2016. The questions regarded: communicate of uncertainties*, comparison of exposures to the natural radiation exposure, flexible limits and reference values in exceptional circumstances, and how to communicate ALARA*. During the Annual Meetings 2016 of the FS also the answers of the other associated societies of IRPA were summarized together with their recommendations.

Most of the recommendations by GONZALEZ et al. (2013) regarded the relationship between radiation protection and the public. In this context also fundamental and practical aspects of the future development of radiation protection were addressed. However, there is also the general agreement that success or failure of radiation protection will widely depend on a successful communication with the public.

Widespread concerns were spoken out frequently also in discussions with members of the FS which can be summarized as follows:
- *Radiation protection has become too complex.*
- *There is too much of protection due to exuberant conservativities.*
- *Optimization without a lower limit is not reasonable and wastes resources.*
- *The ICRP recommendations regarding Radon, the lens of the eye, and the protection of the environment were premature, partially unnecessary, and have disrupted the trust in ICRP.*
- *The reasonability of dose constraints is frequently misunderstood and questioned.*
- *Non-discernable risks are taken into regard too frequently and real ones remain widely unconsidered.*
- *The community of radiation protection is unable to communicate the substance of radiation protection.*
- *How can the LNT-hypothesis be explained understandably?*
- *How can the radiation risk and its uncertainties be explained understandably?*
- *How can the different dose-risk models can be explained to the public?*
- *How is possible to communicate scientifically exact and at the same time understandably, in particular, if there are large uncertainties due to various reasons associated with the issue?*

4.3 Where are the problems?

The theoretical basis of radiation protection is complex and draws upon many disciplines, e.g. physics, chemistry, biology, medicine, and technics (Völkle 2016). Only few specialists understand it in full detail. Unfortunately, the theoretical basis and the practical performance have widely departed so that it is very difficult to implement a complex theory into practice. In spite of this, the practice of radiation protection works – not because of the theoretical basis

– because the legal regulation in spite of some logical flaws mostly can be applied reasonably and practicable.

Such flaws and logical contradictions arise among others from the still existing substantial inequality and perception of natural and man-made radioactivity and radiation and of their associated risks. An example is the perception of the risk due to the exposure to Radon in homes relative to the additional exposures in the close vicinities of nuclear power plants. The exposure caused by Radon in homes is about 2 mSv to 3 mSv per year (with a large variability and a log-normal distribution with the highest doses being 100fold higher) while the exposures due to releases of radioactivity by nuclear power plants are even under extremely conservative assumptions just a few µSv per year or below.

What are the causes of the concerns regarding the actual status of radiation protection? A certainly not complete list of disruptive factors is given below.

Complexity	The complexity of dose terminology, e.g. additional, hypothetical, conservative, total, remaining, expected, avoidable, and avoided doses, and its lacking durability by again and again new proposals by ICRU.
Justification	The lack of justification of limits and reference values including their ethical foundation.
Optimization	The unlimited optimization down to dose zero and the precautionary principle feed the assumption that small and smallest doses are harmful. In this context, it has to be taken into account that protection measures in a limitless optimization need not only additional efforts but may also increase other risks.
Conservativism	Meaningless accumulation of conservativities and lack of realism should be avoided..
Subjective judgement	Natural and man-made radiation exposures continue to be weighted subjectively differently; it is neglected that 1 mSv from natural radiation means the same risk to get a cancer as 1 mSv from man-made radiation.
Risk perception	There is just a insufficient comparison of risks. Since a risk of zero does not exist or is not recognizable, every additional hypothetical risk can only be judged about on the basis of the existing total risk.
Radon	There is a big confusion when dealing with the risks inferred by Radon and the dosimetry of Radon exposure. Note: An example which can be hardly be explained to the general public ist he following. Switzerland applies the new dose conversion coefficients; Germany does not. How to explain this discrepancy? In the case of Radon, which makes up the largest component of the natural radiation exposure, the dosimetric approach of the ICRP is not generally applicable, needs exceptional cases and needs irreproducible chin-ups.
Collective dose	There is a problem with the collective dose, its interpretation, and hypothetical death cases calculated from it. It has to be clarified to which end the collective dose is useful and where its application is not reasonable.
Detectability versus relevance	The contradiction between detectability in measurements, technical feasibility, and relevance of the data for radiation protection has to be resolved.
Environment	The excessive efforts for radiation protection of the environment should be stopped given the fact that there are no effects observed or to be expected for non-human species in planned exposure situations. The statement that humans represent the most sensitive species and that – in consequence –

	non-human species are well protected as long humans are still remains valid. Most probably there are just a few and rather exotic exceptions where this might possibly not the case and where protective measures might be worthwhile to be examined more closely. Moreover, one must never forget that radiation protection of humans aims to the protection of the individual while protection of the environment means protection of species and the diversity of species. Compare in this respect SSK (2016) and VÖLKLE (2006).

In addition to the problems mentioned above there are more big issues regarding the communication with the public. Therefore, it has to be asked:

Complexity	Is radiation protection too complex, e.g. the multiplicative risk model?
Communication	Are the specialists unable to convey the substance of radiation protection in an understandable way?
Holistic occupational protection	How can radiation protection be presented as an integral and normal part of occupational health and safety protection?
Science	How to deal with „alternative facts“ and fake news?
Limitation of collective doses	Can we take responsibility for calculating hundred thousand of hypothetical death cases using minute doses summarized in a collective dose for large populations? The meaning and the limitations of collective dose have to be explained.
Limits of optimization	Do we question ourselves and radiation protection in general if the precautionary principle is unreasonably applied and endless optimization takes place where the optimization efforts are disproportionate comparing the benefit? Optimization must be limited.
„Magic“ of radiation	Radiation protection is in the trap of the „magic“ of radioactivity and radiation since they cannot be experienced by the human senses. Hiroshima, Nagasaki, Chernobyl, and Fukushima have added something threatening to this „magic”. How do we overcome the resulting psychological barriers?
Communication of risk	Why appears it to be impossible to communicate risk in a reasonable way?
Humans in the focus	Do we not care about the sorrows of the people and their safety? Fears have to be taken seriously; the term „radiophobia“ is the wrong term here. Fear of radiation can cause disease.
Particular interests and hidden agenda	It is a particular nuisance that interested groups, politicians, and some media exploit and misuse the people‘s fears of radioactivity and radiation for pursuing their own goals or hidden agenda and do not reframe from misinformation. The public discussions become more and more characterized by incompetence, prejudices, and fake news. How can we escape from this devil’s cycle?
Open questions which have to be answered	Are we putting enough efforts in education, in particular of multiplicators such as teachers, medical practitioners, and journalists? Why are there so few university chairs for radiation protection?
	Do we need more interaction with politicians so that they engage themselves to develop a rationale, risk-competent society without needless fears and in order to prevent fears to be instrumentalized?
	What went wrong if people as soon as they hear the word radiation

	think involuntarily of genetic malformations such as calves with three legs or abnormal children though such abnormalities can also have other causes and have occurred at all times?

4.4 Theses for the solution of the problems

Everything is a question of dose! However, there is a massive discrepancy in language use between the practitioners of radiation protection and different parts of the public when speaking of small doses. For some full-throated critics of the actual system of radiation protection small doses are in the region of 10 µSv per year and below. However, small doses below 1 mSv per year are not real because nobody is in total exposed to such a small dose give the omnipresent and pertaining natural radiation.

Such contributions to the total radiation exposure can only be calculated and are hypothetical ones; they are not relevant neither for the exposure of humans or for their radiation risk. The safety of humans provided by following the legal regulations will demonstrably not be compromised by a *minimis* of 10 µSv per year and it would also not be compromised by a cut-off criterion of 0.1 mSv per year.

The following list contains the most important topics:

Clear terminology	A strict and clear terminology is needed with regard to low, moderate, and high doses. These terms are frequently completely mingled in the public discussion and cause confusion. A good solution is the consequent application of the definition given by UNSCEAR (2012). UNSCEAR defined the dose categories as usual named by experts and in science as low, moderate, and high (UNSCEAR 2012, Annex A und B): „*Low doses were defined by the range of doses below 100 mGy of low-LET radiation, low dose rates by the range below 0.1 mGy per minute (=6 Gy/h). Medium doses are defined as doses in excess of 100 mGy up to 1 Gy. High doses above 1 Gy*." Here the approximation 1 Gy ≈ 1 Sv is justified.
Natural radiation as a reference	The only benchmark for radiation exposures is the natural exposure. The unavoidable part of the natural radiation exposure defines a lower limit of optimization.
Assessment of additional doses only in the general context	If health effects or safety are regarded the additional dose mostly is the wrong quantity. As the total risk is relevant always the total exposure has to be taken into account.
Reduction of conservativites	The representative person according to ICRP 101 is sufficiently conservative for radiation protection; additional conservativities should not be justified by the precautionary principle and be avoided.
Limits of optimization	Too much radiation protection harms because it wastes limited resources that could be better used elsewhere. A too much causes an unjustified redistribution of available resources; thereby other risks can be enhanced or new ones created.
Holistic approach	A holistic approach to radiation protection is needed; measures of optimization must start at the largest risks. Measures of optimization of radiation protections must not increase other risks or create new ones.
Total risk	Always the total doses and the total risk have to be addressed, individual components of the doses have to be clearly named as such, and their

	contribution has to be put into relation to the total dose and the total risk considering their variations with space and time.

4.5 Recommendations for a radiation protection of the future

4.5.1 Communicate safety instead of risk

As pointed out in the second chapter, the history of radiation protection provided a pathway to more safety. On this way, radiation protection has reached a quality which guarantees high safety – provided the rules are obeyed to. It is the same as everywhere in life: noncompliance with the rules means danger. Therefore, radiation protection is also important in the future.

The estimates of the risks associated with radiation exposures stayed constant during the last decades. The knowledge about the dangers associated with radioactivity and radiation is sufficient to provide the highest possible safety by appropriate radiation protection. The actual system of radiation protection with its fundamental principles of justification of exposures, optimizations of the protection by reducing the doses taking into account social and economic aspects, and the limitation of exposures is robust and reduces remaining risks to an acceptable or tolerable level.

A small risk means high safety. A risk of 5×10^{-5} means 99.995% safety, i.e. 1 in 20 000. In other words: a dose limit for the public of 1 mSv per year means a safety of 99.995%. The safety corresponding to a risk should always be considered and also made clear in the communication with the public.

Radiation protection achieves safety!
One should speak of safety instead of risk!

The practitioners of radiation protection define their goals as to protect humans and the environment against the harmful effects of ionizing and non-ionizing radiation. In practice, this means taking care that the regulations are complied with and explaining comprehensively the rationale of protective measures to the affected persons. The purpose of the communication should be to communicate the safety achieved and not to speak of hypothetical risks and to enlarge fears.

For a scientist, risk is the product of the probability that a harmful event may occur multiplied with the extent of loss. This is a mathematical quantity. For normal people, risk means danger and thread and can be the cause of fears. This risk cannot be quantified. Humans are extremely subjective in the assessment of risks. Risks which are taken voluntarily or risks which are presumed to be controllable are taken less serious than those which are imposed by others or are deemed to be uncontrollable, The same holds for risks associated with practices promising a direct gain or profit and the harmful consequences of which will only occur later or just affects others. In spite of the fact that life in the industrialized countries is as safe as never before, we are living increasingly in a society where we are permanently noticing risks and suspecting threads everywhere (RENN 2014). One reason for this behavior may be that we permanently are confronted almost instantly with whatever bad happens in the world by the media. The strive for safety and a feeling of security is a human want. However, we feel that we are losing more and more the opportunity of retreating into our shells.

Further, it has to be considered that ionizing radiation is not discernible by our senses. Feelings of threats and dangers in connection with something, which cannot be felt or seen, to which one is involuntarily exposed and which is uncontrollable, are a product of human phantasy. For a detailed discussion of the perception of radiation risk see Michel (2015).

Unfortunately, the subjective perception of radiation risks frequently is steered or even misguided by information the relevance or truth of which cannot be judged by the individual. Here is a noteworthy room for improvement. Radiation can be reliably detected by relatively simple instruments, much easier than most chemical dangerous substances; just to mention the many death cases due to CO poisoning per year.

The message of radiation protection should be: if the principles of justification, optimization, and limitation of doses are consequently applied, a reasonable and appropriate safety level is guaranteed – in comparison to the other risks of our daily life. Further measures of protection are unnecessary because they do not justify the efforts compared to the benefits. They can be even counterproductive by increasing other risks or creating new ones. To put this into practice it is necessary that the citizens' trust into the practitioners of radiation protection is improved and that the latter are capable to communicate their line of reasoning in an understandable way.

The questions which have to be answered by radiation protection in the future are the following ones: How do we improve our credibility and how do we cope with those who convey biased information to the citizens and cause fears with fake news and "*alternative facts*"? How do we succeed in conveying our own messages comprehensively and unbiased via the media to our fellow citizens? How do we interact with the media which are the organ and at the same time a filter through which we speak to the public? Quite understandably, the media have an expressed instinct of self-preservation which leads to choosing interesting news for publication: radioactivity and radiation are of interest as long they are mystical and dangerous. This has the consequence that many media have interest in the fear-connected mystic and cultivate it accordingly.

4.5.2 Total doses instead of separate (hypothetical or calculated) partial doses

The sentence *"all substances are poisons, there is none which is not a poison; the dose makes the poison*" is attributed to PARACELSUS, a Swiss medic, natural scientist, and philosopher (* 11.11.1493, † 24.09.1541). This sentence is timelessly valid and also applies to radioactivity and radiation. Health effects depend always on the dose, and in fact on the total dose an individual is exposed to.

Therewith, we come to a fundamental problem of today's radiation protection, namely the focusing onto the additional dose from particular human practices instead onto the entire dose an individual is exposed to. It is mostly neglected that the additional dose has to be added to the dose obtained from the natural radiation and that the additional doses frequently are small compared to the natural ones. It is a fact that such low doses alone – as they are calculated from measurements or models – do not exist in reality because there is no place on this earth without natural radiation.

Moreover, one has to take into account that the individual components of the natural radiation exposure are highly variable. UNSCEAR regards a dose range of 1 mSv to 10 mSv per year as a meaningful, but by far do not cover the entire range of natural exposures (UNSCEAR 2000; UNEP 2016). The extremes of the natural exposures are more likely about 100 mSv per year.

The health effects which are epidemiologically discernible and for which a dose-response relationship was demonstrable always rely to cases where a single dose component with exceptionally high values is dominating relative to the natural exposure. This is for instance the case for the survivors of the atomic bombing and for the Uranium miners. In the case of radiation exposure due to Radon in homes, health effects and dose-effect relationship could only be established by pooling of studies with very large populations.

Therefore, the dose-effect relationships are described by models based on a LNT hypothesis and in which the risks coefficients are deduced from the effects observed at high exposures. The LNT-hypothesis is, however, likely conservative and overestimates the effects at doses in the mSv region. In any way, health effects are not discernible at such low doses.

Critical voices regarding the LNT-hypothesis were raised also by scientists because the hypothesis does not allow for a threshold; see e.g. CALABRESE (2015). The critics goes as far as to the assumptions – which is also not provable – that low dose have positive health effects. With regard to the question of the so-called Hormesis see the publication by the late JÜRGEN KIEFER in the StrahlenschutzPraxis 4/2017. Due to the statistical uncertainties in the region of low doses neither positive nor negative health effects of ionizing radiation are discernible, detectable, or attributable (UNSCEAR 2012).

According to today's knowledge, it is unknown whether there is a biological threshold for stochastic health effects. All attempts to determine such a threshold failed due to the variability of the natural radiation exposure and due to the variability of the natural incidences of cancer and leukemia. There is no evidence on which more exact statements regarding the shape of the dose-effect curve in the low-dose region can be based. Moreover, it has to be taken into account that up to now epidemiological studies do not succeed in establishing a complete uncertainty budget. A complete uncertainty budget, however, would be mandatory to answer finally the question for discernibility and detectability of risks.

A multiplicative risk model is recommended for solid cancers, however not for leukemia. For solid cancers, thus the additional risk $R_D(D)$ due to an additional dose D is therefore linked to the already existing and age-dependent, spontaneous risk R_0. For persons having already a higher than average cancer risk – e.g. due to age or living-habits – also the additional risk inferred by a dose D is higher than for those with a lower cancer risk.

The models of radiation risks are valid for average people. There are, however, individual differences in radiation sensitivity, which are influenced by various factors. Such factors are among others genetics and epigenetics (the latter are changes in the function of genes which are not due to mutations or recombination and which in spite of this are transferred to the progeny cells), the immune system of the respective individual, a potential predisposition, as well as synergies with environmental factors. All these are jointly responsible for the large uncertainties in the calculations of risks.

Extremely small components of the radiation exposures can only be calculated on the basis of measured data if they are due to artificial radionuclides using mathematical models because these radionuclides do not occur in nature. For exposures due to natural radionuclides, this is impossible. The variability of the natural background radiation limits downwards the discernibility of man-made changes to the natural radionuclide concentrations and the resulting radiation exposures. Unaffected of this difficulty remains the uncertainty arising from the variability of the incidences of cancer and leukemia. Even if an effect can be measured it does not mean that it is relevant under safety aspects.

In consideration of the total dose, to which a person is exposed, follows that the lowest achievable risk is limited downwards by the natural radiation exposure.

For the assessment of the hazards induced by radiation, the total dose is the relevant quantity. This allows taking into account the natural radiation exposure with its large variations in space and time. The same principle is valid in general when assessing risk.

The natural radiation exposure depends strongly on the place of residence and the living habits. There are places on Earth where humans permanently are exposed to higher natural doses than the region of 1 mSv per year to 10 mSv per year named by UNSCEAR as a normal range. Up to now, however, no significantly elevated incidence of cancer or diseases other potentially caused by radiation could be recognized. It must remain an open question whether the effect of the radiation is negligible or whether the power of the epidemiological studies was insufficient.

Particular contributions to the radiation exposures such as are calculated from measured releases from nuclear installations in normal operation are just hypothetical contributions to the total dose. They are just to be regarded as calculated numbers and not real doses. These calculated minute doses in the sub-mSv region must not be assessed without taken the total doses into account because humans are permanently exposed to natural radiation with doses of some mSv per year and because nobody receives such minute doses. They are just quantities for planning of good practice and allow the introduction of measures to justify, optimize, and limit the releases or to check by modelling and calculations the effectiveness of the measures applied.

Based on these considerations it is expected that ICRP takes into account the total doses when the radiation protection of humans is considered. When dealing with the protection of the environment ICRP has already used the concept of total dose; see e.g. VÖLKLE (2006), PENTREATH et al. (2015), and SSK (2016).

4.5.3 Realism instead of conservativism!

The accumulation of conservativities when calculating doses leads to unreasonable statements and regulations, in particular, if practices or measures have to be justified. This accumulation appears to be mostly a sign of incompetence and uncertainty. In these cases, dose to the representative person according to ICRP 101 (ICRP 2006) should be applied. The dose to the representative person replaces that of the critical group and is similar to that to the most exposed person. It is already sufficiently conservative.

Doses should be calculated as realistically as possible. An important aspect of realism is the accounting for uncertainties and variability. Also the SSK (2004) called for a realistic assessment of radiation exposures. Realism is a sign of competence.

Calculation of hypothetical or maximal contributions to the dose – as they usually are performed – do only make sense for the proof that also in extreme cases of releases the doses will conform with the source-related reference value or limit; e.g. 0.3 mSv per year or 0.2 mSv per year for nuclear power plants in Germany respectively in Switzerland. To ensure this a reasonable conservativity is justified. For the actual exposures, about which the public has to be informed, realistic calculations must be performed. An example for the communication of a realistic assessment could be: *„If you are living in the close proximity of a potential emitter – for instance a nuclear power plant – and if you stay part of your time at the most unfavorable point of exposure, if you partially feed on locally produced foodstuff, and if you use partially water from downstream the plant, the radiation exposure during normal or slightly anomalous operation of the plant would increase by less than 1/1000 relative to what you would receive if the plant were not there. In comparison to the natural radiation exposure this is completely negligible.“*

4.5.4 Optimization must have a lower limit

The natural radiation exposure sets a lower limit for the minimization of potential adverse health effects and thereby for the optimization or the achievable safety. An annual dose of 0.1 mSv already disappears completely in the variability of the natural radiation exposures due to living conditions and life-style. Therefore, a consequent cut-off criterion of 0.1 mSv per year for dose assessments is proposed – widely but not in all cases compatible with actual legislation regarding radiation protection.

Optimization requires a process of consideration by which several factors have to be taken into account. It is easy to say that the dose is to be "minimized". However, without a defined goal above dose zero, the determination of an optimum is difficult. By use of the ALARA principle, the process of consideration can lead to a reasonable result above zero. To this end, the factors have to be differently weighted and not only has the dose to be considered. The list of factors to be weighted is long:

- *the radiation risk in comparison to other already existing risks; e.g. in medical applications of ionizing radiation, but also in all other exposure situations,*
- *the financial efforts needed is taken into account as well as economic disadvantages and benefits,*
- *the potential loss of ones homeland in emergency and existing exposure situations,*
- *the avoidance of wasting resources,*
- *the reasonableness of measures,*
- *whether or not the doses are below the cut-off criterion (de minimis),*
- *whether or not the inferred risk is negligible in comparison to other common risks,*
- *if safety can no more increased without enlarging or creating larger risks,*
- *if a measure of optimization increases already existing risks or creates new ones,*
- *the acceptance in the affected population.*

Optimization in the scientific-technical meaning needs quantitative measures and a loss function for comparisons; it requires a rationale. Optimization in the societal meaning needs to balance differing interests, criteria, and opinions. It needs a democratically legitimated action plan and a just process of decisions.

4.5.5 Planned exposure situations

With a limit of the effective dose of 1 mSv per year for the radiation exposure of members of the public as a consequence of licensed practices, a cut-off criterion of 0.1 mSv per year shall be applied as an end to optimization. It is to point out, however, that optimization with respect to the human radiation exposure is not the same as optimization in order to reduce the releases of man-made radioactivity from a controlled area.

Therefore, the context of release limits, dose limits, and cut-off criteria has to be discussed. 0,1 mSv per year as a cut-off criterion for optimizing the radiation exposure must not be coupled to the limitation of releases. For releases, the principle should be laid down in the regulations, that the state of science and technology is the criterion or that best practice has to be used. That means "*as low as technically feasible taking social and economic aspects into account*". If dose limits are complied with, the stipulation of limits for releases is the task of the regulator and not of operational radiation protection.

The optimization of releases has consequently to be dealt with separately. Presently, the criterion is still the dose potentially received by a person at the most unfavorable place of exposure. For such assessments the representative person according to ICRP 101 is reasonable and sufficient.

For releases of natural radionuclides or residual materials from NORM industries only a reference value of 1mSv per year exists, e.g. in the German StrlSchG (BMUB 2017). If this reference value is not exceeded the authorities have no handle for further measures in the case of natural radioactivity.

Note: It is a fact for man-made radionuclides that the authorities already have taken into account considerable conservativities in the regulations. As a basis serves the 0.3 mSv per year concept. Already in case of the complete exploitation of the allowed limits of releases the calculated doses are lower by an order of magnitude than the limit of 0.3 mSv per year. From the actual releases, doses in the µSv per year region are calculated, i.e. at least two orders of magnitude lower. In a realistic assessment of the doses one would obtain dose values which are again lower by one to two orders of magnitude (VÖLKLE 1984, 2009; Annual reports of ENSI). One ends up at doses for the additional exposure due to releases from nuclear power plants, which are lower by up to five orders of magnitude below the unavoidable natural radiation exposure.

For man-made radionuclides, a dose limit of 1 mSv per year is stipulated in Germany. There are further limits of 0.3 mSv per year each for releases with exhaust air and water. This is compatible with the limits stipulated in Switzerland which demands a maximum of 0.2 mSv per year for the sum of doses over the air and water pathway of all installations at one location. For boiling water reactors the respective limit is 0.3 mSv per year in Switzerland since 0.1 mSv per year are added to account for the direct radiation.

In Germany, a general administrative regulation, the so-called AVV for §47 StrlSchV (BMUB 2012), with a number of non-justifiable conservativities has to be applied which causes additional pressure for the operators to keep releases low. It is, however, only an administrative regulation. A regulation how to keep in line with the state of science and technology is not available in Germany. In Switzerland, no such administrative regulations exist. Here the directives of ENSI (in particular ENSI-G14, 2009) are valid. It is based on models, concepts and recommendations which reveal the actual status of science and technology.

The German law for radiation protection (StrlSchG) sets a limits for the radiation exposures from the sum of licensed practices for natural and an-made radionuclides which is compatible with our approach. The German Commission for Radiological Protection (SSK, www.ssk.de) has recommended a cut-off criterion of 0.1 mSv per year for the sum of the exposures due to licensed practices.

There are certainly methods to legally limit releases of radioactivity as low as possible according to the state of science and technology taking social and economic aspects into account. Not always a dose limit is the adequate tool. The following principle of sustainability should apply to both natural and man-made radionuclides:

If dose limits are not exceeded, nature should not be changed without good reason.

There is a particular example that led to discussions regarding the optimization. It relates to the releases of ^{129}I from reprocessing plants. The releases of ^{129}I from Sellafield (UK) and – in particular – from La Hague (F) have increased the natural isotopic occurrence of ^{129}I in European environment by about six orders of magnitude; e.g. MICHEL et al. (2012). Is this dangerous, just undesired, or completely negligible? For a radionuclide with a half-life of 15.7 Millions of years this is certainly not sustainable since the occurrence of ^{129}I is changed in a for a long time to come. However, the resulting doses in Europe are just about 10 nSv per year (a 10 millionths part of one mSv!). Are measures to reduce the releases justified, at what prize, and what would be their effect? If one puts this in relation to other massive man-made interferences with nature and the environment then a so small consequence appears to be negligible since it likely will remain without adverse effects for humans and the environment.

The example of releases of CO_2 into the atmosphere, which is likely responsible for large parts of the climatic change, may be used as an explanation. Since the beginning of the industrialization, human activities have increased the CO_2 level in the atmosphere by 50 %. Over more than several hundreds of thousands of years it was between 180 ppm and 280 ppm. Today, it exceeds already 400 ppm and increases by 2 ppm each year. The climatic change will have considerable consequences for humankind. This is not doubted by serious scientists any longer. However, we can only speculate about the types and extent of the consequences.

Today, we can measure radionuclides in the environment in extremely low concentration thanks to highly developed measurements techniques and to the fact that radionuclides have their characteristic radiation due to their decay signatures. Dose calculations based on such measurements result in annual dose contributions in the microSv range and below. Such doses are completely irrelevant with regard to the inferred risk or to the question of safety. It is even conceivable to measure an additional exposure of 0.01 µSv per day. Given a background exposure with average doses of 1.2 µSv to 2.9 µSv per day (equivalent to 0.05 µSv/h to 0.12 µSv/h) due to natural radionuclides, such low doses and dose rates are not relevant for safety. Going by plane from Frankfurt to New York means an additional dose of about 0.05 mSv in a day; this further confirms this irrelevance.

If something can be measured it does not yet mean that it is relevant for safety or even dangerous.

The context and the basis for the stipulations of clearance values, exemption values, and limits of surveillance must be better explained. Over-conservative clearance values are to be avoided, in particular those issued by IAEA and EU for unrestricted clearance. Such clearance values are not practicable for the release from surveillance of NORM. such discrepancy must be uncovered, such as for instance the discrepancy between 0.01 mSv per year for clearance and 1 mSv per year as a reference value for restauration of legacies or the release of residues from surveillance (GELLERMANN 2013). In spite of the fact that the question is justified why one should change regulations which works in practice, the discrepancy in handling man-made and natural radioactivity must be addressed.

When measurements are performed for surveillance of environmental radioactivity the German directive for the surveillance of emissions and immissions (REI) and the Integrated Measurement and Information System (IMIS) require detection limits for an individual sample equivalent to 10 µSv per year. This is reasonable even if a cut-off criterion of 0.1 mSv per year is applied. In addition, the European concept of *Dense and Sparse Networks* is not in contrast to the proposed cut-off criterion. While the *Dense Network* for the measurement of the environmental radioactivity is dose oriented with „Reporting Levels“ equivalent to an effective dose of 1 µSv per year, the *Sparse Network* aims to the surveillance of long-term changes of the environmental radioactivity far below any radiological relevance at just a few locations in each member country (EC 2009).

4.5.6 Emergency exposure situations

In emergencies, the limitation of radiation exposures of the workers and the public can be denoted as „the art of the possible“ since the statement holds that „necessity knows no law“. A radiation exposure up to 20 mSv in the first year as a lower reference values in emergency exposure situations appears to be reasonable according to the experience in Japan in the year 2011. Even higher reference values may be tolerable in emergency exposure situations. An upper reference value of 100 mSv in the first year still keeps enough distance to the thresholds of deterministic effects and is sufficient to avoid their occurrence.

In the acute phase of an emergency, optimization is a task for the authorities, which have to organize and recommend adequate measures of protection and to stipulate related regulations. They have in particular to take into account the radiological success of measures in relation to the disadvantages for the affected population. Bevor starting an optimization process, a potential protective measure has to be justified taking into account also the non-radiological disadvantages. Otherwise, considerable detriment can occur as a consequence of a protective measure, as is was the case in Japan as a consequence of evacuations during and after the Fukushima accident.

In the late phase of an accident, in particular in the long-term phase, measures of optimization increasingly require public acceptance with the goal to accomplish the transition into an existing exposure situation socially acceptable as quickly as possible. The final goal of radiation protection is to reduce the exposure below the reference value of the effective dose of 1 mSv per year. However, what cannot be achieved in an emergency is simply impossible.

In emergency exposure situations, the necessary flexibility has to be granted to the authorities to adjust planning and reference values according to the development with time and space of the emergency. It has to be taken into account which means and measures are available, practicable, and economically tolerable. At the same time, other priorities and needs are to be considered in a holistic assessment. It is of outmost importance to cooperate in an emergency with neighboring countries and to harmonize measures and communication with the public. In an emergency, a planning value of 20 mSv in the first year is reasonable for the expected dose of the gross of the population and up to 100 mSv in the first year for individual persons with the final goal to return to a preliminary “normality” with expected doses between 1 mSv per year to 6 mSv per year. It has to be kept in mind also in an emergency that there are regions on Earth where the population lives with annual doses up to 100 mSv without considering this as a threat.

Decisions are in the end a matter of the society the members of which have to weigh the social and economic consequences. The challenge remains, however, how to convince the citizens and the authorities of the necessity of a flexible and situation-oriented system of reference values. In detail, this means that in an exceptional situation an exposure is judged as acceptable or tolerable what would not have been considered as such in planned exposure situations. The experience from the consequences of large evacuations and relocations after large accidents in nuclear power plants should always be kept in mind, since social and economic consequences are more severe than additional exposures within the range of natural radiation exposures.

5.4.7 Existing exposure situations

In existing exposure situations, a lower reference value of 1 mSv per year is reasonable. It proved itself e.g. when remediating the legacies of the German WISMUT company and also in the remediation work of legacies of the Radium industry in Switzerland. A cut-off criterion of 0.1 mSv per year as an end of optimization is sufficiently conservative in existing exposure situations and can also serve as a planning instrument to achieve the long-term goal of potential remediation work of 1 mSv per year for the representative person.

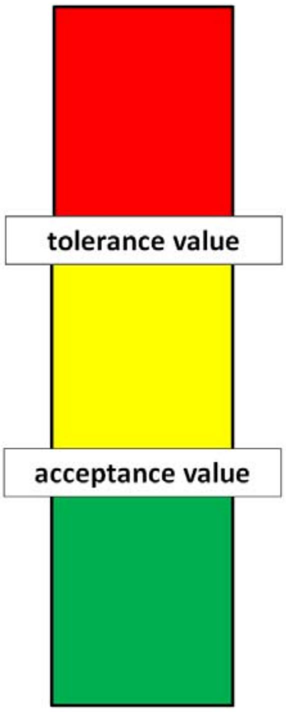
The lower limit of optimization is generally reached if efforts and costs are disproportionate compared to the benefit – in this case the reduction of exposure – or if special circumstances increase other risks of create new ones. Then, optimization measures are at the latest not justified. An optimization measure shall not be performed just because it is feasible but because the effort justifies the benefit and no other risks are increased.

Optimization without benefit – just because it is possible – makes no sense!

5.4.8 A traffic light scheme of radiation protection

The principle of optimization makes only sense in connection with a system of two dose values according to a traffic light model (Fig. 10). Above an upper dose value exposures are not tolerable and measures are mandatory (red); between the two dose values exposures are tolerable if optimization takes place (yellow) and below the lower dose value exposures are acceptable and measures of optimization are neither necessary nor justified (green). Such a concept is easily to communicate. It is easily understandable by the people and should be applied everywhere in radiation protection.

For occupational exposures the upper dose value in such a traffic light scheme is the legal dose limit, the yellow region is deemed tolerable if everything has been done for the reduction of exposures within an optimization process. The green region is upwards limited by a dose value which is equivalent to the legal limit or reference value for the general public. The green region is deemed acceptable. Such a traffic light model is, for instance, used in Germany for work activities with cancerogenic substances for the purpose of occupational safety (AGS 2012, Bender 2014). It has the advantage of being easily communicable. In Switzerland a similar system with tolerance values (yellow) and limits (red) had been used successfully earlier for radionuclides in foodstuff. Unfortunately, it was abandoned for reason of compatibility with the EU and other international recommendations. This is widely regretted by practitioners of radiation protection.



The tolerance value is equivalent to the dose limit in planned exposure situations or to the upper reference value in existing and emergency exposure situations. Exposures above the tolerance value should be considered not tolerable or inacceptable.

In the **yellow region** exposures are deemed as tolerable if everything is done to reduce exposures taking societal and economic aspects into account: ALARA.

The acceptance value is equivalent to the unavoidable part of the natural radiation exposure. Given the variability of the unavoidable natural doses 10% of the acceptance value should be a trivial dose.

For clarification:
Optimization is reduction under constraints.

Fig. 10: *Proposal of a traffic light scheme of radiation protection.*

4.5.9 The Radon complex of problems

Radon and its progeny is certainly an important carcinogen for humans. Thousands of lung cancer cases in miners as a consequence of high exposures to Radon and its progeny have been documented. The fact that also the inhalation of Radon and its progeny in homes is associated with an increased risk of lung cancer for non-smokers – and even much more for smokers – could only be detected in very large populations (Darby et al. 2005).

The risk coefficients, i.e. the risk per unit of exposure given in Bq h m^{-3}, derived from the miner studies and from the studies on Radon in homes are compatible within the statistical uncertainties. However, there is a large number of risk-modifying factors which have to be taken into account when comparing the risks due to the two different exposure situations. Moreover, the exposure-risk-models differ and the non-statistical uncertainties still cannot be quantified.

In November 2009 the ICRP released a *Statement on Radon* which was published together with publication 115 Part 1 *Lung cancer risk from Radon and progeny* (ICRP 2010). In its *Statement on Radon* ICRP lowered the detriment-adjusted risk coefficient for lung cancer due to inhalation of Radon and its progeny for the population of all age classes by about a factor of two and recommended new reference values for Radon in work places and at home.

The *Statement on Radon* by ICRP has already found its reflection in the new EU Basic Safety Standards (EC 2013) and reference values for Radon in work places and in homes are codified in the regulations in Germany in the StrlSchG (BMUB 2017) and in Switzerland in the StSG (Schweizer Bundesrat 2017, BAG 2017).

The ICRP estimates of the risk of lung cancer due to the inhalation of Radon and its progeny as well as the recommended reference values were no longer given in terms of the organ equivalent dose or the effective dose but relative to the time integrated radon concentration in equilibrium with its progeny in the air. The EURATOM Basic Safety Standards and legal regulations codified these new reference values.

With such a direct relationship between the risk and the Radon concentration in the air one avoids the problem of the large uncertainties regarding the dose conversion coefficients when calculating organ equivalent doses or effective doses in mSv from an Radon exposure in units of Bq h m^{-3}. Compared to the earlier dose convention this lowering of the risk coefficients leads to an increase of the effective doses for a given concentration of Radon by about a factor of two. These new dose conversion coefficients of 5.52×10^{-6} mSv per Bq h m^3 for the population and 7.47×10^{-6} mSv per Bq h m^3 for the occupational exposure are already applied by the Swiss Bundesamt für Gesundheit since its annual report 2009.

In its statement of the year 2009 ICRP announced to publish new dose conversion coefficients for Radon in the various exposure situations in the future on the basis of isokinetic and dosimetric models. Thereby, the preliminary dose conversion coefficients derived from the epidemiological approach should be replaced. Only eight years after the ICRP *Statement on Radon* such dose conversion coefficients were published in ICRP 137 (2017). The dose conversion coefficients vary strongly depending of the breathing rates, the characteristics of the aerosols such as the unattached fraction of Radon progeny, the size distribution of the aerosol particles, and the equilibrium factor (*F*).

An additional difficulty arises from the fact that for the same Radon concentrations the risk of lung cancer for smokers is about 20times higher than for life-long non-smokers. For indoor Radon ICRP (2017) recommends dose conversion coefficients which differ by a factor of two depending on whether a seated activity or a physical work is assumed. For ^{222}Rn in homes one obtains according to ICRP (2017) dose conversion coefficients of: $F \cdot 7{,}5 \,\frac{\mathrm{mSv}}{\mathrm{mJ\ h\ m^{-3}}} \mathrel{\hat{=}} F \cdot 16{,}8 \,\frac{\mathrm{mSv}}{\mathrm{MBq\ h\ m^{-3}}} = F \cdot 10{,}6 \,\frac{\mathrm{mSv}}{\mathrm{WLM}}$. This is equivalent to an increase of more than a factor of two compared to the earlier value of ICRP 65 (1993).

When or whether at all these new dose conversion coefficients will be internationally accepted remains presently an open question. Switzerland applies the dose conversion coefficients of the ICRP Statement on Radon already since the BAG Annual Report for 2009 an (BAG 2010). In Germany the Commission on Radiological Protection (SSK, www.ssk.de) recommended in the year 2017 „*… keeping the radon dose coefficients in Germany unchanged until the ICRP provides definitive recommendations on the issue and, furthermore, until international regulatory agreement has been reached on the basis of in-depth scientific discussions. Until that is the case, the radon dose coefficients provided in Section 95(13) of the current German Radiation Protection Ordinance (StrlSchV) should remain valid in current draft legislation as they are within an uncertainty and error range provided by both the epi-*

demiologic and the dosimetric approaches. Any prior national change not agreed upon on an international level would require much greater justification than is currently available.“.

Notwithstanding the not yet finished international discussion of the risk coefficients for Radon and the dosimetric dose conversion coefficients, the confusing communication of the problems around Radon and its progeny have caused a wide-spread discomfort related to the establishment of regulations for radiation protection and to the communication of the radon related risk of lung cancer to the public. The necessity of protection of the public against Radon is not questioned by this discomfort and are independent of this discussion, because the reference values all are given in units of ^{222}Rn activity concentrations in Bq/m^3.

However, the lowering of the risk coefficients by ICRP is not undisputed. ICRP 115 describes the epidemiologic basis of its revision of the risk coefficients. However, the rationale of it are still discussed controversially by experts, in particular how to take into account the risk modifying factors and the fact that the results of the large so-called WISMUT cohort were not yet considered in the calculation of risk coefficients.

The annual mean concentration of Radon in homes in Germany is 50 Bq/m^3. This is equivalent to an average annual effective dose 0.9 mSv assuming a residence time of 19 hours per day. The total annual effective dose due to inhalation of Radon and its progeny, including outdoor and indoor stay, is estimated by the BfS to be 1.1 mSv according to its report to the parliament (BfS 2015). The respective value in Switzerland is 3.2 mSv according to an average Radon concentration of 75 Bq/m^3 and the new dose conversion coefficients according to the ICRP Statement on Radon of 2009.

The average internal radiation exposure due to inhalation of natural radioactivity is about 0.2 mSv assuming permanent stay outdoors (BfS 2000). The concentration of Radon and its progeny varies – as indoors – strongly. For Germany, it is outdoors mostly in a range of 5 Bq/m^3 to 30 Bq/m^3. The median in Germany is 15 Bq/m^3 (BfS 2001). In regions with particular geological conditions which hinder the air exchange, e.g. in valley locations, also higher concentrations can occur. An upper limit of 80 Bq/m^3 can be assumed for the natural concentrations of Radon in outdoor air (BfS 2001).

As mentioned before, the calculation of doses due to the inhalation of Radon depend strongly on conventions for parameters. This applies likewise to the residence times – in Germany one assumes 5 hours per day outdoor stay and 19 hours per day indoors – as to the so-called equilibrium factor which describes to what degree ^{222}Rn is in radioactive equilibrium with its progeny and to the degree to which the progeny is attached to aerosol particles. This is important for the dose the lung receives since the dose is less committed by the Radon gas but by the progeny deposited in the lung. Indoors, the equilibrium factor is between 0.2 and 0.6. As a convention, one assumes 0.4 and outdoors 0.2 (SSK 1994, BfS 2010).

The organ equivalent dose of the lungs is not small. 1 mSv per year effective dose gives an equivalent dose to the lung of about 10 mSv per year with a tissue weighing factor w_T of 12% according to ICRP (2017). However, it is not the total dose for the lung which is relevant for the risk of lung cancer but that to the bronchial which is not an organ according to ICRP. The observation of an increased risk of lung cancer due to the inhalation of Radon and its progeny is not a contradiction to the statement that no observable health effects of radiation exist at small doses. The actual organ equivalent doses received due to inhalation of Radon and its progeny is not small; in one decade already exceeds 100 mSv.

According to the earlier dose conversion coefficients, an effective dose of 0.3 mSv per year cannot be avoided in Europe; according to the new dose conversion coefficients it is 0.6 mSv. It is caused by the Radon concentrations outdoors. These unavoidable annual effective doses represent a natural lower limit to the risk of lung cancer due to inhalation of Radon and its progeny.

The up-to-now communication of the risk due to Radon and the justification of protective measures against Radon by way of the calculation of hypothetical lung cancer deaths is not an example for a good communication. BRÜSKE-HOHLFELD et al. (2006) calculated absolute risks for smokers and non-smokers and gave a number of 1 896 attributable death cases for Germany.

These authors also calculated how many lung cancer deaths in Germany could be saved by the limitation of Radon in homes (BRÜSKE-HOHLFELD et al. 2006). By limiting the Radon concentrations to 400 Bq/m^3, 300 Bq/m^3, 200 Bq/m^3, or 100 Bq/m^3 of the calculated 1 896 death cases 68, ~100, 143, and 302 deaths, respectively, could be avoidable. For 300 Bq/m^3 the authors do not give a number; the number of avoidable death cases for 300 Bq/m^3 was obtained by extrapolation. The relevance of such calculations depends strongly on the accuracy of the risk estimates, because differences between numbers with large uncertainties easily can become insignificant.

According to the results mentioned above, the concentrations of Radon in homes must be lowered considerably to obtain a marked effect in favor of human health for the entire population. Such a reduction of Radon concentrations is actually impossible. Protection against Radon can consequently only reduce the individual risk of people living in high Radon concentrations and not the collective risk. This evidence has not yet been taken notice of. A significant reduction of the individual and the population risk could be achieved, however, by a general ban of smoking. Assuming a relative risk of lung cancer due to inhalation of Radon of 16 % per 100 Bq/m^3, this relative risk is valid for non-smokers and smokers. Since smokers have an about 20times higher absolute risk of lung cancer than non-smokers, the absolute risk due to inhalation of Radon and its progeny is likewise 20times higher for smokers than for non-smokers. Most of the calculated deaths are smokers.

Of the calculated 1 896 death cases – which are frequently cited by the BfS – 1 584 cases were calculated for Radon concentrations below 100 Bq/m^3. Here a particular problem of such calculations becomes evident. By multiplication of a small risk with a large number of exposed people, large numbers of cases can be calculated. Also in a more recent study by AJROUCHE et al (2017) numbers of death cases were calculated. However, in this latter work also the uncertainties of such estimates are discussed and the impossibility to calculate a population risk. The ICRP strongly rejects such an approach. *"It is not appropriate, for the purpose of public health planning, to calculate the hypothetical number of cases of cancer or heritable disease that might be associated with very small radiation doses received by large numbers of people over very long period of time."* (ICRP 103). This leads to the justified question: How relevant is a risk, which only for extreme large populations and at high doses becomes epidemiologically observable? Do we not have something else to care of?

In this context it has also to be mentioned that BRÜSKE-HOHLFELD et al. (2006) assumed a low average values for the average Radon concentration outdoors of 6 Bq/m^3 which is not realistic. A more realistic value would have lowered the calculated number of death cases and demonstrated again the large uncertainty of such estimates for the hypothetical death cases due to Radon.

The revision of the risk coefficients for Radon and the announcement of new dose conversion coefficients by ICRP is a disaster for the practical radiation protection and for the communication of the fundamentals of radiation protection. If the new risk coefficients had been published together with the dose conversion coefficients in the year 2009, no problem would have occurred for radiation protection. Radiation protection would have easily lived with it. The new findings could have been incorporated into the Basic Safety Standards and into the respective legislations and it would have been much easier to communicate these changes.

The confusion would have been avoided that some countries – as for instance Switzerland – apply the dose conversion coefficients of the Statement on Radon while others do not.

Without a scientifically sound rationale for the risk coefficients and without detailed explanations regarding the future dose conversion coefficients severe problems arise for radiation protection; compare SSK (2017). Without any change of the natural radiation exposure, a doubling of the dose conversion coefficients means a doubling of the effective dose. Also for the occupational exposure, it has important consequences. The increase of effective doses by a factor of two means that practicably every worker in NORM and other industries would exceed the reference value for work places of 1 mSv per year. All this would have massive consequences for the practical radiation protection as well as for the communication with the public. All these aspects ICRP should have considered bevor publishing the Statement on Radon.

There is another noteworthy aspect concerning the perception of the risk due to inhalation of Radon. The authorities and the practitioners of radiation protection face large difficulties to persuade the public of the necessity of protection against Radon. The fact that there is a natural carcinogen in our homes is frequently ignored and if remediation measures are considered neglected in view of the costs. Apparently, the wallet is a more sensitive organ than the lungs. Naturally, the attitudes of renters differ from those of the property owners. Also the readily used argument “protection against Radon is protection of smokers” had just few success.

Radon – everybody speaks of it, but nobody takes it serious!

One aspect comes off shortly in the public discussion about the risk due to Radon. It is: how relevant the risk due to Radon is relative to other risks. This is in line with the question for the reasonable use of resources in risk management; see the book by Renn (2014) entitled “The risk paradox or why we fear the wrong?”

The situation with Radon can shortly be summarized as follows: Radon is certainly an important carcinogen, but not the only one. The consequences of smoking and of harmful substances in the air for the incidence of lung cancer are probably higher than those of Radon. Smoking causes lung cancer. For smokers the risk of lung cancer is 20times higher than for non-smokers given the same Radon concentration. Lung cancer makes up about ten percent of all cancers and is the second most cancer of men and the third most for women. Radon exists in the outdoor air; indoors the concentrations are mostly higher – sometimes considerably. The Radon concentrations in homes show approximately a log-normal distribution, i.e. with many low concentrations, a few with high concentrations, and very few with very high concentrations. Consequently, it is reasonable to undertake remediation measures for houses with very high Radon concentrations. Attempts to reduce the average values by remediation measures will fail. This is neither justified considering the effort needed nor is it reasonable.

This discussion leads to the following conclusions: Radiation protection has not achieved its goals regarding Radon. Attempts to cause anxiety in the public of an agent, which is natural and with which humans have lived all time, failed. One builds upon epidemiological data which demonstrate a significant risk for miners, but which are still weak for most Radon concentrations in homes. To calculate hypothetical death cases in order to justify protective measures is not in line with ICRP recommendations.

The public has been confused by the publication of differing strategies, recommendations, reference values, and conversion factors issued by organizations, which did not end up in a harmonized approach. The confusion was further enlarged because different countries act differently and put different conventions into force.

The assessment of the risk due to inhalation of Radon and its progeny is not facilitated by the long latency period for lung cancer of 20 or more years. In the end, epidemiology must necessarily take into account for any concrete case where and how somebody lived during the last 20 years and more.

We recommend that the international community of radiation protection and the respective organizations come to terms with a uniform strategy with regard to limits and reference values as well as with recommendations and their implementation. All this has to be clearly communicated. There is no doubt that buildings with very high Radon concentrations should be remediated. One has, however, to show consideration for the individual circumstances and allow for some degree of discretion for the persons affected. Also in this case, a traffic light scheme would be helpful with an area in red where measures are deemed mandatory, an area in yellow where optimization has to be considered, and one in green where no measures are needed. Such a flexibility would also be reasonable for legacies and NORM.

4.5.10 The dose to the lens of the eye

In April 2011, the ICRP published a „*Statement on Tissue Reactions*“ in which the threshold for deterministic effects to the lens of the eyes, i.e. cataracts, has been lowered to 500 mGy based on more recent epidemiological studies. The ICRP has recommended a limit for the occupational exposure of the lens of the eye – averaged over 5 years – of 20 mSv per year (ICRP 2011). The equivalent dose to the eye should not exceed 50 mSv in any year in order to avoid a hypothetical increase of radiation-induced cataracts of 1%.

In addition, it was pointed that the threshold for heart and brain diseases could likewise be as low as 500 mGy. No references were given for the new epidemiological studies and also no justification for the new setting of thresholds and limits.

This recommendation was already incorporated in the new EU Basic Safety Standards (directive 2013/59/Euratom) and the new limit for the lens of the eye has found its expression in the new legislation in Germany in the StrlSchG (BMUB 2017) and in Switzerland in the StSV (SCHWEIZER BUNDESRAT 2017, BAG 2017). The surveillance of the conformity with the new limits is cause of a considerable complication for dosimetry. The radiation exposure of the lens of the eye, however, is only relevant for a very small part of the occupational exposed persons, namely persons in interventional radiology as well as in some areas for the production of medical application with beta-decaying radionuclides. Also in emergency exposure situations exceedance of the limit can occur.

One has to ask whether the considerable efforts for the surveillance of the doses to the lens of the eye are justified, because, firstly, high doses to the lens of the eye can be avoided by use of appropriate protective measures such as protective goggles, secondly, cataracts of the lens of the eye can be treated easily and with good results, and, thirdly, the radiation exposure of the lens of the eye is only relevant for a small part of the occupational exposed persons. Many practitioners of radiation protection are of the opinion that the new regulations for the protection of the lens of the eye are a manifestation of an exuberant, more bureaucratic, and no longer reasonable radiation protection. The observed significant increase of cataract therapies is due the higher life expectancy and not due to radiation exposures.

4.5.11 Communication with the public

Success or failure of radiation protection depends highly on the communication with the public (VÖLKLE 2016). The paramount question for the public is: What is safe? This question has not yet been answered. This was also recognized by IAEA who accepted this question for its agenda (IAEA 2016). The answer with respect ot the potential dangers of radioactivity and radiation should be:

Radiation protection keeps you safe!

The term risk – in particular, if minute risks are addressed – should be avoided because of different meaning of risk in science and for the public. One has to address risks if a risk factor changes the natural conditions of life significantly, i.e. if it causes a clear increase of the total risk.

For many people, safety is a feeling if one thinks everything is under control. Uncertainty is regarded as unpredictability and helplessness (Slovic 1987, Slovic et al. 2004, Michel 2015). The particular problem of radioactivity and radiation is that one neither can see it, feel it, hear it, nor smell it. This causes a feeling of uncertainty produced by our phantasy in our brain.

Uncertainty in the epistemological sense is an unavoidable phenomenon of the human existence. It has its origin in incomplete and potentially false information which, moreover, is individually understood and processed to different degrees. With this phenomenon humans had and have to live all times. In principle, we are accustomed to making decisions based on our experiences and knowledge even in the presence of incomplete and subjectively assessed information. Otherwise, we could not live at all.

Since radioactivity and radiation are not perceivable by our senses, it is essential to impart the physical, chemical, and biological fundamentals of radiation protection. In order to cope with the uncertainty resulting from the non-perceptibility of radioactivity and radiation competence in radiation protection is as necessary for the general public as for the handling of fire, water, sun, wind, snow, gravity, electricity, chemical, tools, engines, and vehicles. However, regarding radioactivity and radiation our system of education fails while education works fairly well for the other items. In many cases, teachers – themselves untrained and incompetent – even promote the fears of radioactivity and radiation. Both phenomena have not yet became a part of our common culture.

Many fears originate from false or lacking information. They are products of our phantasy nurtured by information that cannot be verified by the individual. Under certain circumstances, such fears can make people ill, more severe than radiation can do.

Such fears have to be taken honestly and have to be dealt with. The term “radiophobia” is out of place under such circumstances. Objective and understandable information can help to handle such fears. Here, health care professional with detailed knowledge about radiation protection and its fundamentals are required. Self-appointed experts and false prophets advocating maverick opinions and not deterring from fake news can do here more harm than good.

We see the following fields of actions where strategies have to be developed.

Professionalizing the information	The information transfer by the expert associations of radiation protection must be professionalized in order to enable them to quickly inform in the case of need before the self-appointed experts forestall them.
Better education	Education in schools has to provide basic knowledge regarding sources and effects of radioactivity and radiation at all grades.
Involving practitioners	The practitioners of radiation protection must not be degraded to a stubborn executers of laws and rules they must be involved in the content design of radiation protection and act responsibly to protect humans against real threats.
Younger genera-	The promotion of the younger generation in radiation protection has to be

tion	improved.
Multiplicators	Multiplicators, such as teachers, physicians, and journalists need expert knowledge regarding sources and effects of radioactivity and radiation. It is of outmost importance to provide them with respective and reliable sources of information.
Better information for the media	Journalists should learn to distinguish fake news from scientifically sound statements. It is important that the expert associations provide respective and reliable sources of information bite-sized and timely.
Beter information for politicians	Politicians should refrain from instrumentalizing fears of radiation for their own agenda. Again, it is important that respective and reliable sources of information be provided to them. The expert societies Should oppose clearly and engaged undesirable developments in politics.
Establishment of a general culture of radiation protection	A culture of radiation protection as – at the same time – safety culture should become a common part of the culture of our societies. According to the present state of radiation protection, this does not mean a call for more safety.
Professionalizing radiation protection	The communication of radiation protection – by the authorities, the scientific community, and the expert associations – should be professionalized. It is of outmost importance to inform timely and competent in the case of need. The information should be provided by well-recognized experts and not by self-appointed ones. In an emergency information is frequently incomplete and no final assessment can be made. Experts do not become more trustworthy if they state that further investigation and measurements are necessary; they should simple say what is known and what is not. The nuisance to present in the media after a profound scientific statement of an expert a contrary opinion of other interested parties or organizations should be abandoned. Science is not politics, but politics should listen to science.

An important aspect of the perception of safety is whether or not a danger, a thread, or a risk appears controllable. It does not matter whether the controllability is real or just believed. Classical examples are the drivers of cars who in spite of about 3 000 deaths by accidents in a year in Germany are convinced that nothing can happen to them because they believe that they have the risk under their control.

The enormous efforts of the automobile industry and of the legislation to make driving safer surely are justified given the actual number of victims of accidents and they show success. A success story with respect to safety culture is the civil aviation. Today, just about 100 persons die per year due to accidents in civil aviation. Road traffic causes still 1.3 million of deaths worldwide, in Europe 26 000 per year.

For the communication of safety – and to explain the safety concept of radiation protection more easily to the public – a traffic light scheme appears to be best suited. Everybody knows the meaning of red, yellow, and green from daily life even if someone is color-blind. It will be understood, even if we term the red region as not tolerable, the green one as acceptable, and the yellow one as the tolerable region of optimization. At workplaces with carcinogenic substances the traffic light scheme also proved to be helpful in the discussion among the social partners (BENDER 2014).

Safety is always depending on the context. What may be tolerable in an emergency or an existing exposure situation may be judged differently in a planned exposure situation. This fact will, for instance when dealing with an emergency or a legacy, is the most difficult aspect to be communicated. The regulator and the practitioner of radiation protection can only give recommendations. The people themselves have in the end to decide for themselves based on their available knowledge. General rules likely cannot be enforced – just the available information can be improved.

The same principle holds for radiation protection, radioactivity and radiation, on the one hand, and for rules of traffic and traffic itself, on the other: As long as there is no accident, one feels safe! The fact that in both cases mostly nothing happens is a consequence of knowing the rules and obeying to the rules.

However, what should remain generally and always acceptable with respect to radioactivity and radiation is nature as it is: unavoidable; and … safer than the unavoidable risk is not achievable!

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