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Radiological Protection of the Unborn Child

Recommendation of the Commission on Radiological Protection and Scientific Grounds

Adopted at the 197th session of the Commission on Radiological Protection on 16/17 December, 2004

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Radiological Protection of the Unborn Child

Recommendation of the Commission on Radiological Protection

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1 Background

The Commission on Radiological Protection was asked to give advice on the practical implications of the absorption of the maximum possible activity values that, under the Radiation Protection Ordinance, may be incorporated in women of child-bearing age occupationally exposed to radiation with regard to incorporation monitoring and compliance with the dose limit for the protection of the unborn child.

The limit placed on the effective dose to occupationally radiation-exposed persons, including women of child-bearing age, is 20 mSv per calendar year (Section 55 paragraph 1 Radiation Protection Ordinance), while the limit placed on the uterine dose to women of child-bearing age is 2 mSv per month (Section 55 paragraph 4 clause 1 Radiation Protection Ordinance). In addition to this, it is necessary to observe organ limits (Section 55 paragraph 2 Radiation Protection Ordinance). For an unborn child exposed to radiation on account of a pregnant woman's employment, the dose from external and internal exposures to radiation from the time the pregnancy is declared to the end of the pregnancy is limited to 1 mSv (Section 55 paragraph 4 clause 2 Radiation Protection Ordinance).

An unborn child's conceivable level of exposure to radiation in the least favourable case due to continuous and single incorporations of radionuclides in the mother was determined on a nuclide-specific basis by the Federal Office for Radiation Protection with the aid of the mathematical metabolic models provided in ICRP 88. At the proposal of the Commission on Radiological Protection, the Federal Office for Radiation Protection considered the following very conservative scenarios:

- the mother's maximum possible exposure due to a continuous intake of activity over 10 years prior to the pregnancy and in the first 10 weeks postconception based on the limits set out in the Radiation Protection Ordinance;

- the mother's maximum possible exposure due to a single intake at the most unfavourable time in the first 10 weeks postconception based on the limits set out in the Radiation Protection Ordinance.

It was assumed in both scenarios that the pregnancy was diagnosed at the end of week 10 postconception. The committed effective dose to age 70 years was calculated. Due, above all, to the increase in the size of their organs, the committed effective dose to age 70 years and the dose received during the pregnancy are approximately equally large for most unborn children exposed to radiation.

Examination of these scenarios found that, with a few exceptions, the dose to the unborn child attributable to the incorporation of radiation in the mother summed up over 70 years is less than that to the mother. The committed effective dose to the unborn child from certain radionuclides may exceed the value of 1 mSv when the dose to the mother reaches the maximum limit.

The Commission on Radiological Protection was therefore asked

1. to examine whether compliance with the limit of 1 mSv effective dose is sufficient for the protection of the unborn child or whether any additional limitation is required for individual organs,

2. to discuss the implications for incorporation monitoring of a maximum committed effective dose of 1 mSv to the subsequently born child to age 70 years under the conditions

   - of a continuous intake of the maximum activity permitted by the limit for occupationally radiation-exposed persons due to incorporation over a period of 10 years and

   - a single intake of the maximum activity permitted by the limit for occupationally radiation-exposed persons as a result of a single incorporation of typical nuclide mixes,

3. to set out the potential and limits of ambient air monitoring for the incorporation monitoring of women of childbearing age

and to submit a recommendation on the basis of the latest advances in science and technology.

2 Results of the model calculations

The detailed results of the model calculations are summarised in the Scientific Grounds. It is to be noted that only the exposure of the unborn child resulting from the incorporation of radionuclides in the mother is covered by the calculations; any possible additional external exposure is not taken into account.

For many radionuclides, a continuous exposure of the mother due to incorporation over 10 years during which the intake received is the maximum permitted by the relevant limits does not represent a problem with regard to compliance with the limit of 1 mSv for the unborn child. However, there is a series of radionuclides from which, under the conservative assumptions of the model calculations, the unborn child may receive a dose exceeding the limit of 1 mSv, in particular following a single intake of the maximum activity permitted by the limit for an occupationally radiation-exposed mother. In some cases, the limit for the unborn child is exceeded even when the dose to the mother is clearly below these limits. The following radionuclides, which are relevant in practice, are especially problematic, in particular if they are present in an easily soluble form: H-3, C-14, P-32, S-35 (research); Mo-99, Tc-99m (medicine); Fe-55, Ag-110, Cs-137 (nuclear technology); Pb-210 (naturally occurring radionuclide); Ni-59, Ni-63 (research and industry); Sr-89, Sr-90 (medicine and nuclear technology). A detailed account of the results of the model calculations for all the radionuclides examined is given in the Scientific Grounds (Table 3-1 for continuous intakes, Table 3-3 for single intakes).

The conservative nature of the modelling of continuous intake lies in the assumption that the intake is the maximum permitted by the dose limit over a period of 10 years due to incorporations in a woman occupationally exposed to radiation. This would be possible in theory, but in practice it is hardly conceivable where radioactive materials are being handled since it would be identified in good time by the in-house radiological protection unit and the principle of minimising exposure to radiation (Section 6 para. 2 Radiation Protection Ordinance) would have to have been contravened for a number of years at least. The monitoring data from German incorporation measuring stations confirm that no such exposures have occurred in the past. In addition to this, it is assumed that the maximum dose permitted by the limits is only received as a result of incorporation. Any additional external exposure prior to the woman

becoming pregnant would reduce the level of the maximum admissible incorporation. The conservative nature of the modelling for a single intake lies in the selection of the timing of the maximum dose permitted by the limit for the mother occupationally exposed to radiation in the first 10 weeks of the pregnancy.

3 Recommendations

Recommendation concerning the question: Is it necessary to limit the dose to individual organs?

The Commission on Radiological Protection does not consider any additional limitation of the dose to individual organs in the unborn child to be necessary provided there is compliance with the limit of 1 mSv committed effective dose to the unborn child. With regard to deterministic radiation damage, doses to developing and formed organs below 100 mGy may be disregarded, as threshold doses have been identified in human beings for malformations in a range from 100 to 200 mGy [ICRP 84, ICRP 90]. For mental retardation, a threshold dose around 300 mGy is accepted for the period from week 8 to week 15 postconception, the period of the highest sensitivity [ICRP 90]. It is to be noted that damage to organs during a pregnancy is always associated with time windows. This means that damage to quite particular organs can only be triggered in certain sensitive phases of organogenesis during the pregnancy. From a radiobiological perspective, therefore, the only doses of radiation that are of significance are those received within these time windows, some of which merely last a few days.

The limitation of the effective dose to the unborn child over the rest of the pregnancy to 1 mSv takes adequate account of stochastic risks (leukaemia and solid tumours). There are currently no grounds to suspect that the risk of a tumour depends on the timing of exposure during the pregnancy.

Recommendation concerning implications for incorporation monitoring

The monitoring of incorporations in occupationally radiation-exposed persons must ensure that an annual dose to a woman of childbearing age of 1 mSv under the least favourable conditions (including acute intakes) is reliably recorded. This also means the dose to the unborn child will be sufficiently reliably determined by the monitoring programme to be implemented. For those radionuclides that are identified in the modelling as “problematic”, the Commission on Radiological Protection suggests special radiological protection and incorporation monitoring arrangements, such as measures for the early identification of contaminations and measures dependant on the radionuclides to be monitored, e.g. a shortening of routine monitoring intervals. It is necessary to examine on a nuclide-specific basis whether the detection sensitivity of the procedures currently used for those radionuclides identified as “problematic” is sufficient and how they could possibly be optimised.

The probability of a single intake, including one below the limit for occupationally radiation-exposed persons, can be markedly reduced if preventive radiological protection measures are taken and the persons concerned behave in accordance with the principles of radiological protection. Regardless of admissible dose or intake values, it is nevertheless not possible to completely exclude an intake of this kind as an extraordinary event. The Commission on Radiological Protection regards it as important that single intakes of this kind are identified at an

early stage, e.g. by workplace monitoring, and can be quantified by effective incorporation measuring.

The Commission on Radiological Protection does not regard ambient air monitoring intended to demonstrate compliance with the dose limit for the unborn child as a suitable method of achieving this goal reliably.

4 Summary

The Commission on Radiological Protection finds that, when certain radionuclides are handled, even if the limits for the mother are complied with under very conservative assumptions, the dose to the unborn child may exceed the limit of 1 mSv once the pregnancy has been declared. This is true, in particular, of a single intake at the least favourable time in a pregnancy that has still not been diagnosed.

The Commission on Radiological Protection sees no need to set dose limits for individual organs in the unborn child.

The Commission on Radiological Protection recommends the maintenance of the practice of defining a “threshold for further investigation” of 6 mSv, which has proved worthwhile in the past in the context of the incorporation monitoring of occupationally radiation-exposed persons. When the dose reaches or exceeds this threshold in an individual case, this triggers the determination of the body dose using standard biokinetic data, subject to case-specific assumptions concerning the relevant conditions of exposure. If the occupationally radiation-exposed person is a woman, it is always necessary to consider the possibility that she is pregnant and, accordingly, determine the level of radiation to which an unborn child she may be carrying is exposed.

The Commission on Radiological Protection recommends that a procedure for the radionuclides recognised as critical be defined that allows the committed effective dose to the unborn child to be determined even before the “threshold for further investigation” of 6 mSv has been reached. A proposal in this respect is made in the Scientific Grounds (Table 4-3 and the comments on this table).

If an occupationally radiation-exposed woman informs the radiological protection officer that she is pregnant, it is recommended that immediate steps be taken to define or determine the activities of the radionuclides incorporated in the mother and assess the committed effective dose to the unborn child resulting from previous intakes of activity.

The Commission on Radiological Protection recommends that special emphasis be placed on the topic of workplace and incorporation monitoring in the training and professional development of radiological protection officers. It is a central duty of the radiological protection officer to largely prevent single intakes in particular, even below the limit for occupationally radiation-exposed persons, by taking suitable measures in the workplace.

Radiological Protection of the Unborn Child

Scientific Grounds
for the Recommendation of the Commission
on Radiological Protection

1 Background

It is the task of radiological protection to protect people from the harmful effects of ionising radiation. This also applies, as a matter of course, to the developing offspring prior to birth. In this context, possible exposure to radiation in the course of the pregnant mother's work is of special significance. The incorporation of radionuclides in a woman of childbearing age prior to the beginning of a pregnancy may contribute to the exposure of her subsequently born child to radiation.

The International Commission on Radiological Protection (ICRP) has addressed this problem and discussed some aspects of it in a number of documents. The ICRP sees no grounds that require the monitoring regime for occupationally radiation-exposed persons to make any distinction between the sexes. The potential risks associated with exposure to radiation are regarded as approximately the same for women and men. However, the ICRP regards increased protection for the unborn child to be necessary as soon as a woman is pregnant [ICRP 88] and refers to earlier recommendations in this respect [ICRP 73].

The ICRP, along with many states inside and outside the European Union, regards radiological protection measures that are equally valid for occupationally exposed women and men as also providing sufficient protection for the unborn child in the first weeks of pregnancy. Once a woman has declared that she is pregnant, further protective measures are required, and not just in terms of radiological protection. In this context, the ICRP therefore suggests organising the pregnant woman's working conditions in such a way that the unborn child does not receive an effective dose in excess of 1 mSv during the remaining period of the pregnancy.

The ICRP sees possible practical problems that could arise for occupationally radiation-exposed women as soon as restrictive limits are laid down for the unborn child. It refers to the fact that this recommendation is often interpreted very restrictively and that it should not be used to unjustifiably disadvantage pregnant women in their work. It notes that the implementation of radiological protection recommendations, in particular source-specific dose limitations, normally ensures adequate protection and that no further restrictions are required for the employment of women [ICRP 73].

The ICRP's recommendations have been incorporated into the EU's basic standards and therefore form the starting point for the German Radiation Protection Ordinance as well. Regulations for the protection of the unborn child when a mother is occupationally exposed to radiation in her work are found in Sections 43, 55 and 95 Radiation Protection Ordinance. The requirements of the basic standards, and consequently the ICRP recommendations, are implemented by the limitation of the cumulative uterine dose over a month, which corresponds in first approximation to the dose to the unborn child during the first weeks of the pregnancy, to 2 mSv and the limitation of the dose from external and internal exposure to radiation to 1 mSv for the period from the woman's declaration that she is pregnant until the birth of the child. Annex VI Part B no. 5 Radiation Protection Ordinance equates the internal exposure of the unborn child with the committed effective dose to the mother, unless the authorities responsible stipulate otherwise.

ICRP 88 supplies mathematical metabolic models that make it possible to determine the dose to the unborn child due to the absorption of radionuclides by future and pregnant mothers. This procedure allows the very rough assessment of internal exposure to radiation in Annex VI Part B

No. 5 Radiation Protection Ordinance to be compared with the results of the direct determination of the dose to the unborn child. Furthermore, these ICRP models make it possible to assess the unborn child's internal exposure to radiation due to the absorption of radionuclides by the future mother in a period prior to the beginning of the pregnancy.

An assessment of the unborn child's exposure to radiation carried out by the Federal Office for Radiation Protection on the basis of the ICRP models shows that, when there is a continuous intake by the future mother at or even, in some cases, below the level of the limits set out in the Radiation Protection Ordinance for occupationally radiation-exposed persons, certain radionuclides may deliver a committed effective dose to the unborn child to age 70 years of around 1 mSv or more during the pregnancy.

The Commission on Radiological Protection was therefore asked

1. to examine whether compliance with the limit of 1 mSv effective dose is sufficient for the protection of the unborn child or whether any additional limitation is required for individual organs,

2. to discuss the implications for incorporation monitoring of a maximum committed effective dose of 1 mSv to the subsequently born child to age 70 years under the conditions

   - of a continuous intake of the maximum activity permitted by the limit for occupationally radiation-exposed persons due to incorporation over a period of 10 years and

   - a single intake of the maximum activity permitted by the limit for occupationally radiation-exposed persons as a result of a single incorporation of typical nuclide mixes,

3. to set out the potential and limits of ambient air monitoring for the incorporation monitoring of women of childbearing age

and to submit a recommendation on the basis of the latest advances in science and technology.

2 Biological effects following prenatal irradiation in humans

2.1 Preliminary remarks

The definition of the terms "embryo" and "fetus" is not uniform in the literature. In this overview, embryo denotes all stages of the unborn child until the conclusion of organogenesis (up to and including week 8 in humans) and fetus denotes all subsequent stages. The term "prenatal organism" is used as a generic term for both the embryo and the fetus. (Note: Organogenesis is usually regarded as concluded at the end of week 7 in humans. For dosimetric reasons, the ICRP has extended this period by one week. See the introduction to Section 3.1).

The prenatal organism exhibits very high proliferation activity, above all in its early stages. It is therefore to be supposed that it is particularly radiosensitive. Both experiments with humans and a large number of animal experiments confirm this assumption. The latest findings are

summarised in a new ICRP publication [ICRP 90]. The present document draws above all on this source, and it has consequently been decided to largely refrain from quoting original literature.

As among adults, non-stochastic (deterministic) and stochastic effects are also to be differentiated in the prenatal organism. The first include death before implantation, morphological-anatomical abnormalities (teratogenic effects) and a series of functional abnormalities. Leukaemia and solid tumours (stochastic effects) can also be induced during prenatal development, but only become manifest several years later.

The effects described all differ with regard to the probability of their occurrence (see Figure 1) and their dose-dependence in general during the different stages of development. The question mark behind genomic instability in Figure 1 refers to the fact that the only data on this effect available to date relate to certain special mouse strains and the extent to which these results can be generalised is not clear; this is true, in particular, of their applicability to humans. There are first indications that the induction of genomic instability in certain mouse strains is not limited to the preimplantation phase, but is also possible in the fetus. Mental retardation is primarily caused by ionising radiation, mainly in weeks 8 to 15 postconception, although a markedly lower but demonstrable risk is also observed in weeks 16 to 25 (see Section 2.2.3).

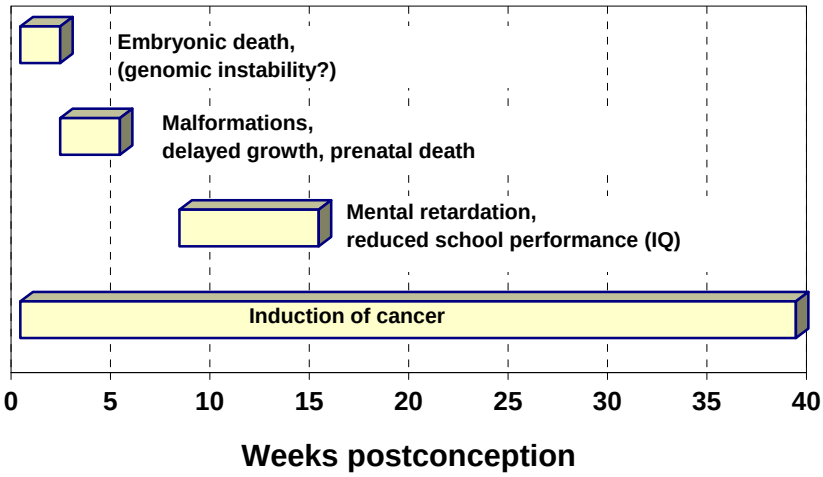

Fig. 1: Time dependence of prenatal effects of radiation

Threshold behaviour is to be assumed for all non-stochastic effects. The threshold doses vary, but all lie above 50 mGy for low-LET radiation.

Few data are available for the assessment of RBE values. In comparison to photons, cyclotron neutrons exhibited RBE values of about 3 with regard to intrauterine deaths, malformations and growth delays. This suggests that giving organ doses in mSv tends to overestimate the risk from high-LET radiation.

There are no data on the effect of incorporated radionuclides in human beings. H-3, P-32, Sr-90, I-131 and Pu-239 have been investigated in animal studies – mainly with mice. Both leukaemias and solid tumours were found in these studies. In general, no clear organ specificity was exhibited, which applies above all when incorporation takes place in the early stages of development.

The only studies on the influence of dose rate have been based on animal experiments that do not provide a clear picture. There are indications that, where the same dose is received, lower dose rates of low-LET radiation have lesser effects, but the database is narrow.

2.2 Special effects

2.2.1 Preimplantation period; main risk: embryonic death

In human beings, the implantation of the embryo in the mucous membrane of the uterus is concluded approximately two weeks postconception. Irradiation during the preimplantation phase results, primarily, in the death of the embryo. The precise level of the threshold dose is not known; above all, there is a lack of comprehensive data for human beings in this field. However, malformations have also been found in special mouse strains following exposure to radiation. The extent to which these results may be generalised has not been clarified.

2.2.2 Organogenesis; main risk: teratogenesis

The formation of the organs begins immediately after implantation. In some cases, exposure to radiation during this period leads to severe developmental abnormalities, affecting above all the central nervous system, the eyes and the skeleton. Cell death in the developing organs is usually regarded as the main mechanism responsible for these effects. Experience of these teratogenic effects has been gained in studies of children who were exposed prenatally in the 1920s because the mother's abdomen was irradiated in an attempt to induce an abortion and children who were irradiated in utero by the atomic bombs dropped on Japan. In its report [ICRP 90], the ICRP assumes a threshold dose of 100 mGy for low-LET radiation, but effects have also been found at levels as low as 50 mGy in animal experiments.

2.2.3 Fetogenesis; main risk: mental retardation

Studies of survivors in Hiroshima and Nagasaki found that irradiation in the periods between weeks 8 and 15 and, with a clearly lower level of risk, weeks 16 and 25 led to – in some cases severe – abnormalities in mental development. This phenomenon was later confirmed by targeted experiments on rats. The inhibition of the division of nerve cells, and the impairment of the migration of the future cerebral cells and formation of the synapses represent the main reasons for this phenomenon. The threshold dose for severe mental retardation in the most sensitive phase (weeks 8-15) is given by the ICRP as 300 mGy. However, it is necessary to note that, in some studies, significant effects on mental performance were demonstrated at levels of 100 mGy and below.

The quantification of a mental abnormality is difficult. Otake et al. [Ota 96] expressly distinguished between "severe mental retardation" and the reduction of IQ (intelligence quotient). By "severe mental retardation", they understood that the children were not able to perform simple calculations, were incapable of holding a simple conversation, could not care for themselves, were "completely unmanageable" or had to be accommodated in residential homes. It is possible to approximate to the dose-dependence of IQ reduction in surveys of school performance with IQ tests using a linear function, which would indicate the lack of a threshold dose. The discussion about this question has still not been concluded.

2.2.4 All stages of pregnancy; risk: leukaemia and solid tumours

It has not hitherto been possible to demonstrate a significant increase in the risk of cancer among persons who were irradiated in utero by the atomic bomb explosions in Japan. By contrast, the British "Oxford Study of Childhood Cancers" comes to the conclusion that a significant rise in leukaemias and, to a lesser extent, solid tumours can be found among children whose mothers were X-rayed during pregnancy at levels as low as 10 mGy and above. This not uncontroversial research was critically evaluated once again a few years ago [Dol 97], when the original conclusions were essentially confirmed. According to these studies, the additional absolute risk coefficient for tumour cases during childhood following in-utero exposure to radiation is 6% per Gray, regardless of the timing of the exposure during the pregnancy. This risk coefficient is fraught with great uncertainties. However, should it be accurate, this would mean that 30 mGy in utero are sufficient to double the frequency of tumours in childhood.

Another aspect is of great significance in this connection. If the statistical relationship found between the frequency of in-utero exposures and the increase in the frequency of childhood tumours were a causal one, then this would show that an increase in the frequency of tumours is demonstrable following doses of radiation of around 10 mGy, which would provide significant support for the LNT ("linear-no-threshold") convention.

By way of qualification, however, it must be pointed out that the results of other studies on the same topic are contradictory and do not confirm the Oxford Study in every case.

2.3 Summary / evaluation: Biological effects following prenatal irradiation

Organ doses below 50 mGy may be disregarded with regard to deterministic radiation damage (malformations). The ICRP assumes threshold doses ranging from 100 to 200 mGy [ICRP 84, ICRP 90].

This also applies for mental retardation induced in weeks 8 to 15 postconception, the period of the highest sensitivity. The ICRP gives a threshold dose of around 300 mGy [ICRP 90].

At present, it is unclear whether the reduction of IQ observed in Hiroshima and Nagasaki points to a threshold dose or whether there is a linear or linear-quadratic dependence. If there is a linear dependence without a threshold dose, then the reduction of IQ following exposure in the most sensitive phase (weeks 8-15 postconception) lies at 25 IQ points per Gy, even taking account of children with severe mental retardation [ICRP 90].

The limitation of the effective dose to 1 mSv for the rest of the pregnancy takes sufficient account of stochastic risks (leukaemia and solid tumours). There are no grounds to suspect that these effects are dependent on the timing of exposure during the pregnancy. It is not possible to demonstrate any organ specificity when radionuclides are incorporated in animal experiments. The Commission on Radiological Protection does not consider an additional limitation of the dose to the unborn child's individual organs to be necessary provided there is compliance with the limit of 1 mSv committed effective dose.

It is, in any case, to be noted that the scenarios discussed here relate to continuous exposures. Since quite particular types of organ damage during pregnancy are always associated with specific time windows and doses outside these time windows do not cause damage to those

organs, mathematically determined organ doses (e.g. committed effective dose to age 70 years) clearly overestimate the risk. Only the radiation dose received in the time window critical for the organ in question is relevant for risk assessment.

3 Exposure of the unborn child to radiation due to the incorporation of radionuclides in the future mother prior to the pregnancy

In the past, the ICRP developed age-specific biokinetic and dosimetric models and used them to derive dose coefficients for the absorption of radionuclides through inhalation and ingestion among the population. Biokinetic models for children of various ages were generated by making appropriate adjustments to model parameters drawn from the models developed for adults [ICRP 56, ICRP 67, ICRP 69, ICRP 71]. No generally accepted models were available for the unborn child in its various stages of development. On the basis of a review of existing biokinetic data, new models have been generated for dose assessment at all stages in the development of the unborn child until birth and published in ICRP 88. This has made it possible to add detail to earlier preliminary recommendations on the assessment of the unborn child's exposure due to radionuclides incorporated in the mother.

3.1 Principles of the models

For dosimetric purposes, two periods of development are distinguished:

- Embryo:
  first stages of development until most organs have been formed; corresponds to the first 8 weeks postconception, i.e. from conception to the end of week 8 postconception (length of embryonic period: 56 days);

- Fetus:
  growth and maturation of individual organs, week 9 postconception to the birth of child (length of fetal period: 210 days).

The uterine dose to the mother due to incorporated radionuclides is used – as in ICRP 53 – for the assessment of the dose to the embryo up to the end of week 8 postconception. By this point, the embryo weighs approximately 10 g. At the beginning of week 9 postconception, it is assumed that the development of the organs is concluded and the fetus can selectively accumulate some elements in individual organs and tissues. Organ and tissue doses are determined on the basis of existing element-specific models and parameters founded on sufficient human data. This is possible for tritiated water (HTO), caesium, iodine, calcium, strontium, barium and radium.

Insufficient human transfer data were available for all other elements, for which data from animal and in-vitro studies as well as information on chemical analogues were used to determine radionuclide deposition in the unborn child. A generic modelling approach is used to determine the associated exposure to radiation. This is based on relative radionuclide concentrations for the fetus and the mother averaged over the whole body. Data from animal experiments were used to determine the concentration ratios, provided that these data had been gathered shortly after incorporation. The conservative assumption was made that the concentration ratio remained

constant over the remaining period of the pregnancy. Together with the mass of the unborn child, this concentration ratio makes it possible to assess the total activity present in the unborn child.

The modelling of the distribution of activity in the body of the unborn child is then based on that of a 3-month-old baby without consideration of excretions. The ICRP regards this procedure for determining the dose to the unborn child as conservative overall [ICRP 88].

The ICRP model is taken as the basis for the determination of the radionuclide intake by the future mother that

1. corresponds to a committed effective dose to the unborn child (until the subsequently born child reaches the age of 70 years) of 1 mSv and

2. does not exceed the limit for occupationally radiation-exposed persons (effective dose or organ dose).

3.2 Continuous inhalation over a period of 10 years

The following scenario was assumed for an occupationally radiation-exposed woman as defined in Section 3 para. 2 no. 31 Radiation Protection Ordinance:

- The dose received is the maximum permitted by the limits set out in Sections 55 and 95 Radiation Protection Ordinance.

- The intake took place continuously through inhalation at a constant intake rate (activity median aerodynamic diameter [AMAD] 5 μm), starting 10 years before the beginning of the pregnancy.

- The intake continued at the same intake rate following the beginning of the pregnancy and stopped at the end of week 10 postconception.

The results of the modelling are summarised in Table 3-1. Column 3 gives the annual maximum activity inhalable by an occupationally radiation-exposed woman of childbearing age at which the dose received complies with the limits set out in Section 55 Radiation Protection Ordinance (effective dose and organ dose) and, at the same time, the committed effective dose to the unborn child does not exceed 1 mSv. Column 4 contains the maximum activity inhalable by occupationally radiation-exposed persons at which the doses they receive comply with the limits set out in Section 55 Radiation Protection Ordinance.

Column 5 gives the quotient derived from column 3 and column 4 (without rounding as in the columns to the left). This value is always ≤ 1. If the value is equal to one, compliance with the limits set out in Section 55 Radiation Protection Ordinance for the mother will also ensure compliance with the limit for the unborn child. If it is less than one, compliance with the limits set out in Section 55 Radiation Protection Ordinance for the mother does not ensure compliance with the limit of 1 mSv for the unborn child.

*Tab. 3-1: Annual maximum activities **continuously** inhalable by an occupationally radiation-exposed woman on the basis of the limits set out in Section 55 (1, 2) Radiation Protection Ordinance and the limit of 1 mSv committed effective dose to the unborn child (to age 70 years) set out in Section 55 (4) Radiation Protection Ordinance*

Radionuclide	Respiratory tract model absorption type (see Tab. 3-2)	Maximum inhalable activity **Continuous intake**		Quotient: Column 3 / Column 4
		Compliance with Section 55 (1, 2) (effective dose and organ dose for women of childbearing age) **and** Section 55 (4) (max. 1 mSv for the unborn child) Bq	Compliance **only** with Section 55 (1, 2) (effective dose and organ dose for women of childbearing age) Bq	
1	*2*	*3*	*4*	*5*
H-3	OBT	5 E+07	5 E+08	0,10
	HTO	1 E+08	1 E+09	0,12
C-14	CO_2	4 E+08	3 E+09	0,13
	CO	5 E+09	3 E+10	0,22
	Methane	7 E+08	7 E+09	0,10
	Vap.	3 E+06	3 E+07	0,10
P-32	F	9 E+05	1 E+07	0,08
	M	1 E+06	7 E+06	0,15
S-35	SO_2	2 E+07	2 E+08	0,12
	CS_2	2 E+06	3 E+07	0,08
	F	4 E+07	3 E+08	0,15
	M	2 E+07		1,00
Ca-45	M	2 E+06	9 E+06	0,29
Ca-47	M	6 E+06	1 E+07	0,62
Fe-55	F	1 E+06	2 E+07	0,07
	M	3 E+06	5 E+07	0,07
Fe-59	F	1 E+06	7 E+06	0,15
	M	3 E+06	6 E+06	0,50
Co-57	M	2 E+07	5 E+07	0,48
	S	3 E+07		1,00
Co-58	M	1 E+07		1,00
	S	1 E+07		1,00
Co-60	M	6 E+05	3 E+06	0,23
	S	9 E+05	1 E+06	0,80
Ni-59	Vap.	4 E+05	2 E+07	0,02
	F	1 E+06	9 E+07	0,01
	M	4 E+06	2 E+08	0,02
Ni-63	Vap.	2 E+05	1 E+07	0,02
	F	5 E+05	4 E+07	0,01
	M	2 E+06	6 E+07	0,03

Radionuclide	Respiratory tract model absorption type (see Tab. 3-2)	Maximum inhalable activity **Continuous intake** Compliance with Section 55 (1, 2) (effective dose and organ dose for women of childbearing age) **and** Section 55 (4) (max. 1 mSv for the unborn child) Bq	Compliance **only** with Section 55 (1, 2) (effective dose and organ dose for women of childbearing age) Bq	Quotient: Column 3 / Column 4
1	*2*	*3*	*4*	*5*
Zn-65	S	5 E+05	7 E+06	0,08
Se-75	F	1 E+06	1 E+07	0,10
	M	2 E+06	1 E+07	0,14
Se-79	F	8 E+05	8 E+06	0,09
	M	8 E+05	6 E+06	0,13
Sr-89	F	3 E+06	9 E+06	0,35
	S	4 E+06		1,00
Sr-90	F	3 E+05		1,00
	S	2 E+05		1,00
Y-90	M	1 E+07		1,00
	S	1 E+07		1,00
Zr-95	F	2 E+06	5 E+06	0,31
	M	6 E+06		1,00
	S	5 E+06		1,00
Nb-94	M	1 E+06	3 E+06	0,42
	S	8 E+05		1,00
Nb-95	M	2 E+07		1,00
	S	2 E+07		1,00
Mo-99	F	3 E+07	6 E+07	0,55
	S	2 E+07		1,00
Tc-99	F	3 E+07	5 E+07	0,59
	M	6 E+06		1,00
Tc-99m	F	1 E+09		1,00
	M	7 E+08		1,00
Ru-103	Vap.	4 E+06	2 E+07	0,23
	F	8 E+06	3 E+07	0,26
	M	1 E+07		1,00
	S	9 E+06		1,00
Ru-106	Vap.	3 E+05	1 E+06	0,26
	F	5 E+05	2 E+06	0,26
	M	1 E+06		1,00
	S	6 E+05		1,00
Ag-108m	F	2 E+05	3 E+06	0,09
	M	7 E+05	4 E+06	0,18
	S	1 E+06	1 E+06	0,93

Radionuclide	Respiratory tract model absorption type (see Tab. 3-2)	Maximum inhalable activity **Continuous intake** Compliance with Section 55 (1, 2) (effective dose and organ dose for women of childbearing age) **and** Section 55 (4) (max. 1 mSv for the unborn child) Bq	Compliance **only** with Section 55 (1, 2) (effective dose and organ dose for women of childbearing age) Bq	Quotient: Column 3 / Column 4
1	*2*	*3*	*4*	*5*
Ag-110m	F	4 E+05	3 E+06	0,14
	M	1 E+06	3 E+06	0,34
	S	2 E+06	3 E+06	0,70
Sb-124	F	3 E+06	1 E+07	0,29
	M	4 E+06		1,00
Sb-125	F	6 E+05	1 E+07	0,06
	M	3 E+06	6 E+06	0,45
Sb-126	F	5 E+06	1 E+07	0,45
	M	6 E+06		1,00
Sb-127	F	2 E+07	3 E+07	0,90
	M	1 E+07		1,00
Te-127m	Vap.	6 E+05	2 E+06	0,26
	F	1 E+06	5 E+06	0,26
	M	3 E+06	3 E+06	0,84
Te-129m	Vap.	2 E+06	3 E+06	0,52
	F	4 E+06	8 E+06	0,51
	M	4 E+06		1,00
Te-131m	Vap.	8 E+06		1,00
	F	2 E+07		1,00
	M	1 E+07		1,00
Te-132	Vap.	4 E+06		1,00
	F	7 E+06	8 E+06	0,88
	M	7 E+06		1,00
I-125	Vap.	1 E+06		1,00
	Meth.	1 E+06		1,00
	F	2 E+06		1,00
I-129	Vap.	2 E+05		1,00
	Meth.	2 E+05		1,00
	F	3 E+05	3 E+05	0,91
I-131	Vap.	8 E+05		1,00
	Meth.	1 E+06		1,00
	F	1 E+06		1,00
I-132	Vap.	6 E+07		1,00
	Meth.	9 E+07		1,00
	F	1 E+08		1,00

Radionuclide	Respiratory tract model absorption type (see Tab. 3-2)	Maximum inhalable activity **Continuous intake**		Quotient: Column 3 / Column 4
		Compliance with Section 55 (1, 2) (effective dose and organ dose for women of childbearing age) **and** Section 55 (4) (max. 1 mSv for the unborn child) Bq	Compliance **only** with Section 55 (1, 2) (effective dose and organ dose for women of childbearing age) Bq	
1	*2*	*3*	*4*	*5*
I-133	Vap.	4 E+06		1,00
	Meth.	5 E+06		1,00
	F	8 E+06		1,00
I-134	Vap.	1 E+08		1,00
	Meth.	4 E+08		1,00
	F	3 E+08		1,00
I-135	Vap.	2 E+07		1,00
	Meth.	2 E+07		1,00
	F	4 E+07		1,00
Cs-134	F	4 E+05	2 E+06	0,19
Cs-136	F	3 E+06	1 E+07	0,24
Cs-137	F	6 E+05	3 E+06	0,20
Ba-133	F	2 E+06	9 E+06	0,24
Ba-140	F	1 E+07		1,00
Ce-141	M	7 E+06		1,00
	S	6 E+06		1,00
Ce-144	M	9 E+05		1,00
	S	7 E+05		1,00
Sm-153	M	3 E+07		1,00
Yb-169	M	1 E+07		1,00
	S	8 E+06		1,00
Re-186	F	3 E+07		1,00
	M	2 E+07		1,00
Pb-210	F	9 E+02	8 E+03	0,10
Po-210	F	2 E+04		1,00
	M	9 E+03		1,00
Ra-224	M	8 E+03		1,00
Ra-226	M	9 E+03		1,00
Ra-228	M	8 E+03		1,00
Th-228	M	9 E+02		1,00
	S	7 E+02		1,00
Th-230	M	2 E+02		1,00
	S	2 E+03		1,00
Th-232	M	2 E+02		1,00
	S	2 E+03		1,00

Radionuclide	Respiratory tract model absorption type (see Tab. 3-2)	Maximum inhalable activity **Continuous intake**		Quotient: Column 3 / Column 4
		Compliance with Section 55 (1, 2) (effective dose and organ dose for women of childbearing age) **and** Section 55 (4) (max. 1 mSv for the unborn child) Bq	Compliance **only** with Section 55 (1, 2) (effective dose and organ dose for women of childbearing age) Bq	
1	*2*	*3*	*4*	*5*
Th-234	M	4 E+06		1,00
	S	3 E+06		1,00
U-232	F	9 E+02	3 E+03	0,29
	M	3 E+03	4 E+03	0,69
	S	8 E+02		1,00
U-233	F	6 E+03	3 E+04	0,24
	M	9 E+03		1,00
	S	3 E+03		1,00
U-234	F	6 E+03	3 E+04	0,23
	M	9 E+03		1,00
	S	3 E+03		1,00
U-235	F	7 E+03	3 E+04	0,24
	M	1 E+04		1,00
	S	3 E+03		1,00
U-236	F	7 E+03	3 E+04	0,24
	M	1 E+04		1,00
	S	3 E+03		1,00
U-238	F	7 E+03	3 E+04	0,23
	M	1 E+04		1,00
	S	4 E+03		1,00
Np-237	M	4 E+02		1,00
Np-239	M	2 E+07		1,00
Pu-238	M	3 E+02		1,00
	S	2 E+03		1,00
Pu-239	M	3 E+02		1,00
	S	2 E+03		1,00
Pu-240	M	3 E+02		1,00
	S	2 E+03		1,00
Pu-241	M	2 E+04		1,00
	S	2 E+05		1,00
Am-241	M	3 E+02		1,00
Am-243	M	3 E+02		1,00
Cm-242	M	5 E+03		1,00
Cm-244	M	5 E+02		1,00

The ICRP respiratory tract model defines special absorption types for the classification of inhaled radionuclides (Table 3-2). These types are based on the chemical form and metabolic behaviour of the radionuclide inhaled.

Tab. 3-1: Abbreviations for respiratory tract model absorption types and special chemical compounds

F	“Fast” absorption type
M	“Medium” absorption type
S	“Slow” absorption type
Vap.	Vapour, vaporous
Meth.	Methyl compound
OBT	Organically bound tritium
HTO	Tritiated water
CO	Carbon monoxide
CO_2	Carbon dioxide
SO_2	Sulphur dioxide
CS_2	Carbon disulphide

In addition to the radionuclides considered in ICRP 88, Table 3-1 includes the following radionuclides used in nuclear medicine: Y-90, Sm-153, Yb-169 and Re-186. It was assumed that the activity concentrations for each of these radionuclides are the same in the fetus, placenta and mother. The calculations show that these radionuclides do not represent any radiological protection problem for the unborn child.

Some radionuclides of the U-238, U-235 and Th-232 decay chains are included in Table 3-1. Many radionuclides of these decay chains are very short-lived, with physical half-lives of a few minutes or less. The contribution these radionuclides make to the dose to the unborn child is negligible.

If it is assumed that natural decay chain radionuclides not mentioned above behave similarly to the mother nuclide from the point of view of the unborn child’s exposure to radiation, no further radiological protection problems are to be expected for the unborn child.

The radionuclides Bi-210, Bi-212, Pb-212, Ra-223, Th-227, Ac-227, Ac-228 and Pa-231 have half-lives of more than 1 hour. Due to its comparatively short half-life (10.6 hours), Pb-212 does not have the same significance for the dose to the unborn child as Pb-210. Ra-223 and Th-227 behave similarly to the other isotopes of radium and thorium.

Bismuth is assumed to have the same activity concentration ratio in the fetus and the mother as polonium, actinium the same as americium and protactinium the same as neptunium [ICRP 88].

3.3 Single intake due to inhalation at the least favourable time for a dose to the unborn child

The following scenario was assumed for an occupationally radiation-exposed woman as defined in Section 3 para. 2 no. 31 Radiation Protection Ordinance:

- the intake takes place once through inhalation (AMAD 5 μm);
- the intake takes place at the least favourable time for a dose to the unborn child by the end of week 10 postconception at the latest. It is assumed that by this point the pregnancy has been declared and further employment-related intakes of activity are therefore to be excluded.

Depending on the radionuclide in question, the least favourable time for a single intake – a function of its half-life and element-specific biokinetic data – lies in the narrow time window between the beginning of the pregnancy and the end of the period under consideration (in this case, the end of week 10 postconception). To simplify matters, the calculations carried out considered acute intakes of activity by the mother in three iterative steps at the beginning of the pregnancy (conception), at the end of week 5 postconception and at the end of week 10. This does not account for the least favourable time under all circumstances. The least favourable time for the intake of "long-lived" radionuclides from the point of view of the level of the radiation dose (though not necessarily radiobiological effects) is at conception, the least favourable time for the intake of "short-lived" radionuclides is the end of week 10 postconception. Radionuclides with half-lives between the two are taken into account by means of the calculation for the middle of this interval. The model assumes that no further intake takes place after week 10 postconception. It is assumed that the least favourable of the results for these three intake times will not deviate significantly from the result for the least favourable intake time. The results of the nuclide-specific calculations are presented in Table 3-3.

As with the results when a continuous intake is assumed (Section 3.2), it is evident that for some radionuclides an acute intake by the mother below the limits for occupationally radiation-exposed persons results in a committed effective dose to the unborn child of less than 1 mSv, but for other radionuclides the dose reaches or exceeds the limit for the unborn child, even when the mother's intakes are below the limits for occupationally radiation-exposed persons.

*Tab. 3-3: Annual maximum activities inhalable in a **single** intake by an occupationally radiation-exposed woman on the basis of the limits set out in Section 55 (1, 2) Radiation Protection Ordinance and the limit of 1 mSv committed effective dose to the unborn child (to age 70) set out in Section 55 (4) Radiation Protection Ordinance*

Radionuclide	Respiratory tract model absorption type (see Tab. 3-2)	Maximum inhalable activity **Single intake**		Quotient: Column 3 / Column 4
		Compliance with Section 55 (1, 2) (effective dose and organ dose for women of childbearing age) **and** Section 55 (4) (max. 1 mSv for the unborn child) Bq	Compliance **only** with Section 55 (1, 2) (effective dose and organ dose for women of childbearing age) Bq	
1	*2*	*3*	*4*	*5*
H-3	OBT	1 E+07	5 E+08	0,03
	HTO	3 E+07	1 E+09	0,03
C-14	CO_2	1 E+08	3 E+09	0,04
	CO	4 E+08	3 E+10	0,02
	Methane	2 E+08	7 E+09	0,03
	Vap.	1 E+06	3 E+07	0,03
P-32	F	7 E+04	1 E+07	0,01
	M	9 E+04	7 E+06	0,01
S-35	SO_2	6 E+06	2 E+08	0,03
	CS_2	6 E+05	3 E+07	0,02
	F	1 E+07	3 E+08	0,04
	M	1 E+07	2 E+07	0,71
Ca-45	M	2 E+05	9 E+06	0,03
Ca-47	M	3 E+05	1 E+07	0,03
Fe-55	F	3 E+06	2 E+07	0,23
	M	1 E+07	5 E+07	0,26
Fe-59	F	4 E+05	7 E+06	0,05
	M	1 E+06	6 E+06	0,17
Co-57	M	1 E+07	5 E+07	0,22
	S	2 E+07	3 E+07	0,51
Co-58	M	3 E+06	1 E+07	0,18
	S	3 E+06	1 E+07	0,27
Co-60	M	6 E+05	3 E+06	0,21
	S	9 E+05	1 E+06	0,77
Ni-59	Vap.	1 E+06	2 E+07	0,06
	F	6 E+06	9 E+07	0,06
	M	2 E+07	2 E+08	0,10
Ni-63	Vap.	6 E+05	1 E+07	0,06
	F	2 E+06	4 E+07	0,06
	M	9 E+06	6 E+07	0,14
Zn-65	S	5 E+05	7 E+06	0,07

Radionuclide	Respiratory tract model absorption type (see Tab. 3-2)	Maximum inhalable activity **Single intake**		Quotient: Column 3 / Column 4
		Compliance with Section 55 (1, 2) (effective dose and organ dose for women of childbearing age) **and** Section 55 (4) (max. 1 mSv for the unborn child) Bq	Compliance **only** with Section 55 (1, 2) (effective dose and organ dose for women of childbearing age) Bq	
1	*2*	*3*	*4*	*5*
Se-75	F	7 E+05	1 E+07	0,05
	M	8 E+05	1 E+07	0,07
Se-79	F	7 E+05	8 E+06	0,09
	M	8 E+05	6 E+06	0,13
Sr-89	F	1 E+05	9 E+06	0,01
	S	4 E+06		1,00
Sr-90	F	5 E+04	3 E+05	0,20
	S	2 E+05		1,00
Zr-95	F	7 E+05	5 E+06	0,15
	M	2 E+06	6 E+06	0,43
	S	4 E+06	5 E+06	0,81
Nb-94	M	1 E+06	3 E+06	0,36
	S	8 E+05		1,00
Nb-95	M	4 E+06	2 E+07	0,25
	S	5 E+06	2 E+07	0,30
Mo-99	F	5 E+06	6 E+07	0,09
	S	2 E+07	2 E+07	0,95
Tc-99	F	3 E+06	5 E+07	0,05
	M	3 E+06	6 E+06	0,46
Tc-99m	F	1 E+08	1 E+09	0,14
	M	2 E+08	7 E+08	0,24
Ru-103	Vap.	1 E+06	2 E+07	0,06
	F	2 E+06	3 E+07	0,07
	M	5 E+06	1 E+07	0,45
	S	6 E+06	9 E+06	0,65
Ru-106	Vap.	2 E+05	1 E+06	0,14
	F	3 E+05	2 E+06	0,14
	M	1 E+06		1,00
	S	6 E+05		1,00
Ag-108m	F	2 E+05	3 E+06	0,09
	M	7 E+05	4 E+06	0,17
	S	1 E+06		1,00
Ag-110m	F	2 E+05	3 E+06	0,07
	M	5 E+05	3 E+06	0,16
	S	8 E+05	3 E+06	0,30

Radionuclide	Respiratory tract model absorption type (see Tab. 3-2)	Maximum inhalable activity **Single intake**		Quotient: Column 3 / Column 4
		Compliance with Section 55 (1, 2) (effective dose and organ dose for women of childbearing age) **and** Section 55 (4) (max. 1 mSv for the unborn child) Bq	Compliance **only** with Section 55 (1, 2) (effective dose and organ dose for women of childbearing age) Bq	
1	*2*	*3*	*4*	*5*
Sb-124	F	8 E+05	1 E+07	0,08
	M	2 E+06	4 E+06	0,39
Sb-125	F	1 E+06	1 E+07	0,11
	M	4 E+06	6 E+06	0,59
Sb-126	F	1 E+06	1 E+07	0,09
	M	1 E+06	6 E+06	0,21
Sb-127	F	3 E+06	3 E+07	0,13
	M	6 E+06	1 E+07	0,53
Te-127m	Vap.	2 E+05	2 E+06	0,11
	F	6 E+05	5 E+06	0,11
	M	1 E+06	3 E+06	0,36
Te-129m	Vap.	3 E+05	3 E+06	0,09
	F	7 E+05	8 E+06	0,09
	M	7 E+05	4 E+06	0,19
Te-131m	Vap.	3 E+06	8 E+06	0,38
	F	5 E+06	2 E+07	0,30
	M	5 E+06	1 E+07	0,40
Te-132	Vap.	1 E+06	4 E+06	0,26
	F	2 E+06	8 E+06	0,23
	M	2 E+06	7 E+06	0,29
I-125	Vap.	6 E+05	1 E+06	0,53
	Meth.	8 E+05	1 E+06	0,54
	F	1 E+06	2 E+06	0,57
I-129	Vap.	5 E+04	2 E+05	0,32
	Meth.	7 E+04	2 E+05	0,33
	F	9 E+04	3 E+05	0,30
I-131	Vap.	8 E+05		1,00
	Meth.	1 E+06		1,00
	F	1 E+06		1,00
I-132	Vap.	3 E+07	6 E+07	0,42
	Meth.	3 E+07	9 E+07	0,36
	F	5 E+07	1 E+08	0,48
I-133	Vap.	4 E+06		1,00
	Meth.	5 E+06		1,00
	F	8 E+06		1,00

Radionuclide	Respiratory tract model absorption type (see Tab. 3-2)	Maximum inhalable activity **Single intake**		Quotient: Column 3 / Column 4
		Compliance with Section 55 (1, 2) (effective dose and organ dose for women of childbearing age) **and** Section 55 (4) (max. 1 mSv for the unborn child) Bq	Compliance **only** with Section 55 (1, 2) (effective dose and organ dose for women of childbearing age) Bq	
1	*2*	*3*	*4*	*5*
I-134	Vap.	6 E+07	1 E+08	0,47
	Meth.	7 E+07	4 E+08	0,18
	F	1 E+08	3 E+08	0,43
I-135	Vap.	2 E+07	2 E+07	0,85
	Meth.	2 E+07	2 E+07	0,94
	F	3 E+07	4 E+07	0,84
Cs-134	F	2 E+05	2 E+06	0,09
Cs-136	F	6 E+05	1 E+07	0,06
Cs-137	F	3 E+05	3 E+06	0,10
Ba-133	F	3 E+06	9 E+06	0,31
Ba-140	F	9 E+05	1 E+07	0,07
Ce-141	M	7 E+06		1,00
	S	6 E+06		1,00
Ce-144	M	9 E+05		1,00
	S	7 E+05		1,00
Pb-210	F	6 E+03	8 E+03	0,67
Po-210	F	6 E+03	2 E+04	0,31
	M	9 E+03		1,00
Ra-224	M	8 E+03		1,00
Ra-226	M	7 E+03	9 E+03	0,81
Ra-228	M	8 E+03		1,00
Th-228	M	9 E+02		1,00
	S	7 E+02		1,00
Th-230	M	2 E+02		1,00
	S	2 E+03		1,00
Th-232	M	2 E+02		1,00
	S	2 E+03		1,00
Th-234	M	4 E+06		1,00
	S	3 E+06		1,00
U-232	F	2 E+03	3 E+03	0,65
	M	4 E+03		1,00
	S	8 E+02		1,00
U-233	F	4 E+03	3 E+04	0,16
	M	9 E+03		1,00
	S	3 E+03		1,00

Radionuclide	Respiratory tract model absorption type (see Tab. 3-2)	Maximum inhalable activity **Single intake**		Quotient: Column 3 / Column 4
		Compliance with Section 55 (1, 2) (effective dose and organ dose for women of childbearing age) **and** Section 55 (4) (max. 1 mSv for the unborn child) Bq	Compliance **only** with Section 55 (1, 2) (effective dose and organ dose for women of childbearing age) Bq	
1	*2*	*3*	*4*	*5*
U-234	F	4 E+03	3 E+04	0,15
	M	9 E+03		1,00
	S	3 E+03		1,00
U-235	F	5 E+03	3 E+04	0,17
	M	1 E+04		1,00
	S	3 E+03		1,00
U-236	F	4 E+03	3 E+04	0,16
	M	1 E+04		1,00
	S	3 E+03		1,00
U-238	F	5 E+03	3 E+04	0,16
	M	1 E+04		1,00
	S	4 E+03		1,00
Np-237	M	4 E+02		1,00
Np-239	M	2 E+07		1,00
Pu-238	M	3 E+02		1,00
	S	2 E+03		1,00
Pu-239	M	3 E+02		1,00
	S	2 E+03		1,00
Pu-240	M	3 E+02		1,00
	S	2 E+03		1,00
Pu-241	M	2 E+04		1,00
	S	2 E+05		1,00
Am-241	M	3 E+02		1,00
Am-243	M	3 E+02		1,00
Cm-242	M	5 E+03		1,00
Cm-244	M	5 E+02		1,00

4 Significance of the modelling results for practice

4.1 Incorporation monitoring

4.1.1 Persons subject to compulsory monitoring

Monitoring of body doses is necessary for persons who have access to controlled areas where they could receive a dose of more than 1 mSv in a calendar year from external and internal exposure to radiation (Section 40 Radiation Protection Ordinance). Incorporation monitoring is required as soon as there is a potential risk of incorporation from open radioactive materials. Apart from controlled areas, this also applies to monitored areas where it is possible to receive an effective dose of more than 1 mSv in a calendar year due to the incorporation of radioactive materials. When, in addition to internal exposure to radiation, external sources also contribute to overall exposure, the proportion of the dose attributable to external exposures is to be accounted for and, in consequence, the dose criterion for the commencement of incorporation monitoring ("monitoring threshold") of 1 mSv per calendar year reduced accordingly.

It has proved worthwhile to orient the type and extent of monitoring towards the potential incorporation risk and implement two forms of monitoring on this basis. Monitoring based on incorporation risk could, for example, be implemented as proposed in Table 4-1.

It is the task of the radiological protection officer to assess an employee's potential incorporation risk before he or she starts work in a controlled area and to assign him or her to the appropriate monitoring regime. The obligation to determine personal body dose values arises when it is possible for the potential incorporation risk in a calendar year to reach effective dose values of 1 mSv or more or values of one tenth or more of the limits for organ doses set out in Section 55 para. 2 Radiation Protection Ordinance. Exceptions may, with the consent of the authorities, be made for persons whose potential incorporation risk is definitely below the specified dose threshold. Compliance with the dose threshold can be demonstrated by means of operational control measurements (threshold measurements).

Tab. 4-1: Concept for monitoring based on incorporation risk

Monitoring requirement (Potential dose range)	Work in controlled area (radiation protection area) involving incorporation risk	
	≥ 1mSv	< 1mSv
Monitoring goal	Determination of personal body dose values	Demonstration: Exposure < monitoring threshold; Real-time indicator measurements
Legal basis	Section 40 (1) clause 1 Radiation Protection Ordinance	Section 40 (1) clause 3 Radiation Protection Ordinance
Monitoring procedures and responsibilities	Regular incorporation monitoring: - in-vivo procedures / in-vitro procedures at measuring stations specified by the authorities - ambient air measurements – responsibility lies with the radiological protection officer *(accompanying measurements with in-vivo / in-vitro procedures)* *Incorporation risk > 6 mSv: personal procedures only (in-vivo, in-vitro, PAS)*	Regular threshold value measurements (with calibrated devices) - of body activity - of ambient air activity Responsibility lies with the radiological protection officer

(PAS: Personal Air Sampler)

Workplaces at which regular incorporation measuring may be required are found, for example:

- in medicine: therapy with Beta radiators (e.g. P-32, Y-90, I-131) and nuclear-medical diagnostics;
- in trade, industry, research and other fields: the handling of open radioactive substances in radiochemical laboratories, the handling of open radioactive substances in industrial process technologies, the processing of plutonium and transuranium elements and the manufacture of products that contain radioactive materials (lamps, welding electrodes, earthing systems, etc.);
- in nuclear facilities: the normal operation of facilities (nuclear power stations, research reactors), the normal operation of facilities for the production and reprocessing of fuel elements, maintenance and repair work, and the inspection and decommissioning of nuclear facilities;

- at accelerators: radionuclide production using accelerators (cyclotrons) in accordance with regulations, the operation of neutron generators and accelerators used for scientific purposes with a terminal electron energy of more than 8 MeV or a terminal ion energy of more than 3 MeV per nucleon (e.g. tandem accelerators, cyclotrons and synchrotrons).

4.1.2 Requirements placed on incorporation monitoring

The monitoring of incorporations in occupationally radiation-exposed persons must ensure that an annual dose at the level of the monitoring threshold is identified, which may make shorter monitoring intervals necessary in individual cases. The sensitivity of the measuring procedures deployed must be sufficient for an incorporation to be identified during any monitoring interval when it results in a committed effective dose equal to the fraction of the monitoring threshold dose proportional to that interval. Suitable incorporation monitoring procedures for the radionuclides considered in this recommendation are given in the guidelines on incorporation monitoring (currently in draft).

In order to take account of the interests of the radiological protection of the unborn child in the incorporation monitoring of occupationally radiation-exposed women, including those who are unaware they are pregnant, it is also necessary to regularly determine the notional committed effective dose to the unborn child as soon as a woman’s exposure reaches a radionuclide-specific dose threshold. When this is done, earlier intakes of activity by the woman should be considered, subject to case-specific assumptions.

Table 4-2 gives the threshold doses of individual radionuclides derived from the exposure scenarios considered for the calculation of the intakes required to reach the notional dose limit of 1 mSv committed effective dose to age 70 years.

Tab. 4-2: Radionuclide-specific dose thresholds for women of childbearing age at which it is necessary to determine the notional committed effective dose to the unborn child

Radionuclide		Dose threshold Annual dose to a woman at which it is necessary to determine the notional committed effective dose to the unborn child in mSv		
1		*2*	*3*	*4*
Nuclide	Chem. compound / absorption type	Acute intake	Continuous intake	Most restrictive value from columns 3 and 4
H-3	OBT	0,5	2	0,5
	HTO	0,5	2	0,5
C-14	CO_2	0,9	3	0,9
	CO	0,3	4	0,3
	Meth.	0,6	2	0,6
	Vap.	0,6	2	0,6
P-32	F	0,1	2	0,1
	M	0,3	3	0,3
S-35	SO_2	0,7	2	0,7
	CS_2	0,4	2	0,4
	F	0,8	3	0,8
	M	14	20	14
Ca-45	M	0,6	6	0,6
Ca-47	M	0,6	12	0,6
Fe-55	F	5	1	1
	M	5	1	1
Fe-59	F	1	3	1
	M	3	10	3
Co-57	M	4	10	4
	S	10	20	10
Co-58	M	4	13	4
	S	5	20	5
Co-60	M	4	5	4
	S	15	16	15
Ni-59	Vap.	1	0,3	0,3
	F	1	0,3	0,3
	M	2	0,4	0,4
Ni-63	Vap.	1	0,3	0,3
	F	1	0,3	0,3
	M	3	0,6	0,6
Zn-65	S	1	2	1
Se-75	F	0,9	2	0,9
	M	1	3	1
Se-79	F	1	1	1
	M	3	3	3
Sr-89	F	0,2	5	0,2
	S	20	20	20
Sr-90	F	2	9	2
	S	20	20	20

Radionuclide		Dose threshold Annual dose to a woman at which it is necessary to determine the notional committed effective dose to the unborn child in mSv		
1		*2*	*3*	*4*
Nuclide	Chem. compound / absorption type	Acute intake	Continuous intake	Most restrictive value from columns 3 and 4
Zr-95	F	2	5	2
	M	9	20	9
	S	16	20	16
Nb-94	M	7	8	7
	S	20	20	20
Nb-95	M	5	20	5
	S	6	20	6
Mo-99	F	2	11	2
	S	19	20	19
Tc-99	F	1	12	1
Tc-99	M	9	20	9
Tc-99m	F	3	20	3
	M	5	20	5
Ru-103	Vap.	1	5	1
	F	1	5	1
	M	9	20	9
	S	13	20	13
Ru-106	Vap.	3	5	3
	F	3	5	3
	M	20	20	20
	S	20	20	20
Ag-108m	F	2	2	2
	M	3	4	3
	S	20	19	19
Ag-110m	F	1	3	1
	M	3	7	3
	S	6	14	6
Sb-124	F	2	6	2
	M	8	20	8
Sb-125	F	2	1	1
	M	12	9	9
Sb-126	F	2	9	2
	M	4	20	4
Sb-127	F	3	18	3
	M	11	20	11
Te-127m	Vap.	1	3	1
	F	1	3	1
	M	7	17	7
Te-129m	Vap.	1	6	1
	F	1	8	1
	M	4	20	4
Te-131m	Vap.	8	20	8
	F	6	20	6
	M	8	20	8

Radionuclide		Dose threshold Annual dose to a woman at which it is necessary to determine the notional committed effective dose to the unborn child in mSv		
1		*2*	*3*	*4*
Nuclide	Chem. compound / absorption type	Acute intake	Continuous intake	Most restrictive value from columns 3 and 4
Te-132	Vap.	5	20	5
	F	5	18	5
	M	6	20	6
I-125	Vap.	8	20	8
	Meth.	8	20	8
	F	8	20	8
I-129	Vap.	5	20	5
	Meth.	5	20	5
	F	5	14	5
I-131	Vap.	20	20	20
	Meth.	20	20	20
	F	20	20	20
I-132	Vap.	6	20	6
	Meth.	7	20	7
	F	10	20	10
I-133	Vap.	20	20	20
	Meth.	20	20	20
	F	20	20	20
I-134	Vap.	9	20	9
	Meth.	4	20	4
	F	9	20	9
I-135	Vap.	16	20	16
	Meth.	15	20	15
	F	14	20	14
Cs-134	F	2	4	2
Cs-136	F	1	5	1
Cs-137	F	2	4	2
Ba-133	F	5	4	4
Ba-140	F	1	20	1
Ce-141	M	20	20	20
	S	20	20	20
Ce-144	M	20	20	20
	S	20	20	20
Pb-210	F	6	0,9	0,9
Po-210	F	4	16	4
	M	20	20	20
Ra-224	M	20	20	20
Ra-226	M	16	20	16
Ra-228	M	20	20	20
Th-228	M	20	20	20
	S	20	20	20
Th-230	M	20	20	20
	S	20	20	20

Radionuclide		Dose threshold Annual dose to a woman at which it is necessary to determine the notional committed effective dose to the unborn child in mSv		
1		*2*	*3*	*4*
Nuclide	Chem. compound / absorption type	Acute intake	Continuous intake	Most restrictive value from columns 3 and 4
Th-232	M	20	3	3
	S	20	20	20
Th-234	M	20	20	20
	S	20	20	20
U-232	F	13	6	6
	M	20	14	14
	S	20	20	20
U-233	F	3	5	3
	M	20	20	20
	S	20	20	20
U-234	F	3	5	3
	M	20	20	20
	S	20	20	20
U-235	F	3	5	3
	M	20	20	20
	S	20	20	20
U-236	F	3	5	3
	M	20	20	20
	S	20	20	20
U-238	F	3	5	3
	M	20	20	20
	S	20	20	20
Np-237	M	20	20	20
Np-239	M	20	20	20
Pu-238	M	20	20	20
	S	20	20	20
Pu-239	M	20	20	20
	S	20	20	20
Pu-240	M	20	20	20
	S	20	20	20
Pu-241	M	20	20	20
	S	20	20	20
Am-241	M	20	20	20
Am-243	M	20	20	20
Cm-242	M	20	20	20
Cm-244	M	20	20	20

When these results are applied in day-to-day operations, the radiological protection officer must consider and separately evaluate the various conditions of – sometimes combined – continuous and single intakes in specific individual cases, which is very difficult. The results are marked by great uncertainties. The procedure described below could, following thorough examination, come into question as a way of putting practicable arrangements in place. It should be expressly

emphasised that the Commission on Radiological Protection regards this proposal as a conceivable option and therefore does not at present wish to pre-empt any conclusive regulations.

It is regarded as important for radiological protection practice to only consider the most restrictive value found from the two scenarios (column 4 of Table 4-2) when deciding whether to commence the incorporation monitoring of a woman of childbearing age ("monitoring threshold") and the routine determination of the notional dose to an unborn child from specific nuclides (Table 4-3). Section 40 (1) clause 1 Radiation Protection Ordinance alone provides a basis for the commencement of the monitoring of occupationally radiation-exposed women – and also men – at doses of 1 mSv or above.

Furthermore, the Commission on Radiological Protection recommends the maintenance of the practice of defining a "threshold for further investigation" of 6 mSv, which has proved worthwhile in the past in the incorporation monitoring of occupationally radiation-exposed persons. When this threshold is reached or exceeded, the body dose has to be determined in each individual case using standard biokinetic data, subject to case-specific assumptions concerning the relevant conditions of exposure. If the person occupationally exposed to radiation is a woman, the unborn child's notional exposure to radiation must always be determined. This is why radionuclides with a dose threshold (column 4 of Table 4-2) above this "threshold for further investigation" are not listed in Table 4-3.

In a procedure of this kind, the exposure of the unborn child is monitored with sufficient reliability by the monitoring programme to be implemented for the mother. Safety factors are provided:

- by the exclusive consideration of the most restrictive dose threshold found in the two scenarios,
- by the number of incorporation monitoring measurements per annum when there is a continuous intake,
- by the fact that the requirements placed on the monitoring programme are oriented towards the committed effective dose to the mother over 50 years (and not that to the unborn child) and
- by the scenarios on which the dose assessment is based.

The Commission on Radiological Protection wishes to draw attention to the fact that not every occasion on which the proportional intake admissible during a particular time interval is exceeded by an occupationally radiation-exposed mother inevitably results in the dose limit for the unborn child being exceeded as well, provided the monitoring programme consists of more than one incorporation monitoring measurement per year and the incorporation conditions do not remain unchanged throughout the year.

Tab. 4-3: Radionuclide-specific dose thresholds for women of childbearing age at which it is necessary to determine the notional committed effective dose to the unborn child below the threshold for further investigation

Radionuclide	**Dose threshold** Annual dose to the woman at which it is necessary to determine the notional committed effective dose to the unborn child; most restrictive value for either continuous or single intake in mSv
P-32 (F)	0.1
Sr-89 (F)	0.2
C-14 (CO) ; P-32 (M) ; Ni-59 (F) ; Ni-59 (Vap.) ; Ni-63 (F) ; Ni-63 (Vap.)	0.3
S-35 (CS_2) ; Ni-59 (M)	0.4
H-3 (OBT) ; H-3 (HTO)	0.5
C-14 (Vap.) ; C-14 (Meth.) ; Ca-45 (M) ; Ca-47 (M) ; Ni-63 (M)	0.6
S-35 (SO_2)	0.7
S-35 (F)	0.8
C-14 (CO_2) ; Se-75 (F) , Pb-210 (F)	0.9
Fe-55 (M) ; Fe-55 (F) ; Fe-59 (F) ; Zn-65 (S) ; Se-75 (M) ; Se-79 (F) ; Tc-99 (F) ; Ru-103 (F) ; Ru-103 (Vap.) ; Ag-110m (F) ; Sb-125 (F) ; Te-127m (F) ; Te-127m (Vap.) ; Te-129m (F) ; Te-129m(Vap.) ; Cs-136 (F) ; Ba-140 (F)	1
Sr-90 (F) ; Zr-95 (F) ; Mo-99 (F) ; Ag-108m (F) ; Sb-124 (F) ; Sb-126 (F) ; Cs-134 (F) ; Cs-137 (F)	2
Fe-59 (M) ; Se-79 (M) ; Ru-106 (F) ; Ru-106 (Vap.) ; Tc-99m (F) ; Ag-108m (M) ; Ag-110m (M) ; Sb-127 (F) ; Th-232 (M) ; U-233 (F) ; U-234 (F) ; U-235 (F) ; U-236 (F) ; U-238 (F)	3
Co-57 (M) ; Co-58 (M) ; Co-60 (M) ; Sb-126 (M) ; Te-129m (M) ; Ba-133 (F) ; I-134 (Meth.) ; Po-210 (F)	4
Co-58 (S) ; Nb-95 (M) ; Tc-99m (M) ; I-129 (F) ; I-129 (Vap.) ; I-129 (Meth.) ; Te-132 (Vap.) ; Te-132 (F)	5

As a matter of principle, the Commission on Radiological Protection recommends that the committed effective dose to the unborn child be determined as soon as a woman informs her employer she is pregnant.

Measurements of the concentration of activity in ambient air do not usually supply sufficiently reliable information for the determination of individual doses. In particular, problems with the representativeness of the sampling can contribute to considerable uncertainties. However, like other radiological protection monitoring measures, the monitoring of ambient air activity can serve a warning function, contributing to the identification of extraordinary operational conditions that could make individual incorporation monitoring necessary.

4.2 Significance of "harmful" radionuclides for radiological protection practice when there is a continuous intake

The model calculations for continuous intake accord special significance to the Ni isotopes Ni-59 and Ni-63. These are found in enclosed systems as foils in ion mobility spectrometers or ion capture detectors (e.g. in HPLC or gas chromatography). An increased exposure of the unborn child to radiation at levels higher than 1 mSv/a is only to be feared when devices are defective, resulting in continuous incorporation in the future mother, which is excluded in practice provided that operations are conducted in accordance with the regulations. The Commission on Radiological Protection recommends that contamination controls be routinely carried out in the course of the recurrent testing of these devices. Regular incorporation monitoring measures are not required provided devices that prove to have leakages do not continue to be operated, which is to be assumed on technical grounds.

Ambient air contaminations in technical (nuclear) facilities may also contain nickel as a component of the nuclide vector found at these locations. The greatest ambient air contaminations are to be expected when opening components, decommissioning plants and working on or processing plant components and the waste generated during decommissioning. Respiratory protection measures are taken as a matter of principle at workplaces of this kind. The activity concentrations measured at individual facilities show that, even without these measures, the resulting notional committed effective dose to the unborn child is less than 1 mSv.

A continuous intake of the maximum dose permitted by the limit for occupationally radiation-exposed persons over a longer period of time is to be excluded where functioning workplace monitoring is in place. In this respect, the scenario modelled for continuous intake represents an upper envelope for the real exposures of the unborn child determined under worst-case conditions and in no way reflects real workplace and exposure conditions.

4.3 Significance of "harmful" radionuclides for radiological protection practice when there is a single intake

In the exposure scenarios assumed here involving a single intake, the unborn child receives the highest exposures in the narrow time window of the first 10 weeks postconception from the radionuclides H-3, C-14, P-32, S-35 (SO_2, CS_2, F), Ca-45, Ca-47, Se-75 (F) and Sr-89 (F). For many other radionuclides in Table 3-3, a single inhalation of the maximum activity permitted by the limits set out in Sections 55 and 95 Radiation Protection Ordinance in the narrow time window between the beginning of the pregnancy and the end of week 10 postconception ("unfavourable time") also results in a notional committed effective dose to the unborn child of > 1 mSv.

A single intake of the maximum activity permitted by the limit for occupationally radiation-exposed persons can largely be precluded if preventive radiological protection measures are taken and the persons concerned behave in accordance with the principles of radiological protection. The data in Table 3-3 make it clear that single intakes, some far below the limit for occupationally radiation-exposed persons, may result in doses exceeding the notional committed effective dose to the unborn child of 1 mSv.

It is regarded as important that occupationally radiation-exposed persons be made aware of these issues and instructed accordingly, and that compliance with preventive radiological protection

measures also be monitored to an appropriate extent.

High single intakes are not to be regarded as planned or plannable exposures to radiation, not least against the background of the generally accepted principle of minimising exposure to radiation. Nevertheless, an intake of this kind by occupationally radiation-exposed persons cannot be completely excluded, regardless of admissible dose or intake values. The Commission on Radiological Protection considers it to be important that such single intakes are identified at an early stage, e.g. by means of workplace monitoring, and quantified using incorporation monitoring measures.

4.4 Practical experience of incorporation monitoring

Information about the actual incorporations found in occupationally radiation-exposed women in the course of incorporation monitoring is important for the evaluation of the effectiveness and practical significance of measures to limit the unborn child's exposure to radiation. A survey of official and non-official measuring stations in Germany (VKTA Rossendorf, LFU Kulmbach, FANP Lingen, Framatome Erlangen) found that, over the last few years, only a very few occupationally radiation-exposed persons in the fields of nuclear technology, decommissioning projects, medicine and research had received doses above 1 mSv in a year due to incorporation. This is confirmed by corresponding figures from the Federal Office for Radiation Protection on the data it holds concerning occupational exposure to radiation in 2002 (Table 4-4). These figures did not systematically record persons who are currently (still) not subject to monitoring, i.e. persons for whom it was not necessary to expect a dose of (to date) more than 5 mSv (according to the guidelines still in force at present).

Tab. 4-4: Cumulative distributions of effective doses due to incorporation in occupationally radiation-exposed persons registered with the Radiological Protection Register of the Federal Office for Radiation Protection in 2002 [Fra 04]

Effective dose in mSv	All	M	F	F < 45	All < 18
All	661	613	48	26	1
> 0.0	377	362	25	13	1
> 0.2	25	24	1	1	0
> 0.4	20	19	1	1	
> 0.6	17	17	0	0	
> 0.8	15	15			
> 1.0	12	12			
> 1.5	11	11			
> 2.0	9	9			
> 2.5	5	5			
> 3.0	4	4			
> 4.0	4	4			
> 5.0	3	3			
> 6.0	3	3			
> 7.5	2	2			
> 10.0	0	0			

4.5 Summary: Exposure scenarios and implications for practice

In order to be able to evaluate the extent to which current radiological protection monitoring ensures the protection of the unborn child, the committed effective doses to the occupationally radiation-exposed woman and the unborn child were modelled for two "enveloping" exposure scenarios, which were consciously chosen to be very conservative. In this modelling, firstly, a continuous intake of the maximum possible radionuclide activity inhalable over a period of 10 years permitted by the relevant dose limits for occupationally radiation-exposed persons and, secondly, a single intake at the same level at the least favourable time for the exposure of the unborn child were assumed.

The Commission on Radiological Protection is aware of the strongly conservative nature of the assumptions made in the model calculations, in particular for "continuous intake". In practice, even where there is only inadequate workplace monitoring, it is very highly improbable that incorporations of the maximum activity permitted by the limits for the mother could take place over several years.

Furthermore, the future mother's burden from previous exposures due to continuous incorporation does not represent a planning variable, but an existing situation that must be possible to detect. These conditions are to be taken into account when evaluating the results determined on the basis of these model assumptions.

A single intake of the maximum activity permitted by the limit or below by occupationally radiation-exposed persons may be largely precluded if preventive radiological protection measures are taken and the persons concerned behave in accordance with the principles of radiological protection. It is regarded as an essential task of radiological protection monitoring in the workplace to identify situations that could lead to an intake of this kind and take remedial measures in good time.

Regardless of the admissible dose or intake values, an intake of this kind is, nevertheless, not to be completely excluded as an extraordinary event. The Commission on Radiological Protection regards it as important that single intakes of this kind are identified at an early stage, e.g. by workplace monitoring, and quantified using incorporation monitoring measures. It therefore recommends that, in the training of radiological protection officers, special emphasis be placed on this point when covering specialist technical issues.

The monitoring of incorporations in occupationally radiation-exposed persons must ensure that an annual dose of 1 mSv is reliably identified. This may mean that shorter monitoring intervals are required for certain radionuclides and the detection sensitivity of the preferred procedure needs to be adjusted accordingly. This ensures the notional dose to the unborn child is recorded sufficiently reliably by the monitoring programme to be implemented for occupationally radiation-exposed women.

For the radionuclides identified as "problematic" when continuous intakes were modelled, the incorporation of which even below an effective dose to the mother of 1 mSv may result in the notional committed effective dose to the unborn child exceeding 1 mSv, the Commission on Radiological Protection suggests that special radiological protection and incorporation monitoring arrangements be provided for, such as measures for the prevention and early identification of contaminations, the shortening of the routine monitoring intervals as appropriate and the routine determination of the notional committed effective dose to the unborn child as

soon as the dose to the woman is found to have reached a radionuclide-specific threshold.

Aside from their application in routine monitoring, the use of ambient air data for the incorporation monitoring of women of childbearing age with the purpose of demonstrating compliance with the dose limit for the unborn child is not a sufficiently reliable procedure due to the great uncertainty concerning the representativeness of the sampling and the levels of detection sensitivity achieved. Nevertheless, the Commission on Radiological Protection regards the deployment of ambient air monitoring as a form of incorporation monitoring that is expedient in other contexts.

It is recommended that, when an occupationally radiation-exposed woman declares she is pregnant to the radiological protection officer, immediate steps be taken to determine the activity of the radionuclides incorporated in the mother and assess whether the committed effective dose to the unborn child due to prior intakes of activity could exceed the value of 1 mSv.

The Commission on Radiological Protection regards the protection of the unborn child currently provided for in Sections 55 and 95 Radiation Protection Ordinance in the form

- of the limitation of the uterine dose to 2 mSv/month for women of childbearing age and
- the limitation of the dose to the unborn child to 1 mSv from the point when the pregnancy is declared, subject to case-specific assumptions about the pregnant woman’s prior incorporations,

to be adequate.

This judgement is based on the results of the model calculations and practical experience of incorporation monitoring.

The ICRP regards the protection of the unborn child to be assured as soon as it is oriented towards that of the “general population”. The implementation of this recommendation goes beyond the ICRP standard that has gained general international acceptance and involves the danger that women may be disadvantaged in their work. The Commission on Radiological Protection refers expressly to the fact that this recommendation does not in any way represent a justification for women to be disadvantaged as occupationally radiation-exposed persons in comparison to the status quo ante but, at the same time, should also be understood as a challenge to further optimise concrete workplace conditions.

5 References

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