Radiological Assessment of Radioactive Contamination on Private Clothing

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Abstract

In the very rare cases where private clothing of persons working in a nuclear installation are inadvertently contaminated and this contamination is not detected when leaving the facility, there may be radiological consequences for this person as well as for members of his or her family. The VGB (Technische Vereinigung der Grosskraftwerksbetreiber) in Germany has detailedly investigated the spread of contamination in nuclear power plants. Part of this evaluation programme was a radiological analysis which has been carried out by Brenk Systemplanung GmbH (Aachen/Germany).

The radiological analysis started with the definition of the source term. It is highly unlikely that activities of more than 5 kBq Co 60 could leave a plant undetected on the body or the clothes. Nevertheless activities up to 50 kBq and different nuclide vectors were regarded. It has been found that Co 60 is the most important contaminant.

The radiological analysis focusses on two types of contamination: particles and surface contamination. The pathways by which such a contamination can lead to an exposure by external irradiation or by ingestion depend on the type of contamination and are analysed in detail. For example, a particle could be retained in pockets or other parts of clothing and may lead to prolonged external irradiation until the piece of clothing is washed. - The analysis is performed on the basis of conservative to realistic assumptions. It yields the following results (based on deterministic and probabilistic models):

- Surface contamination may lead to only small doses in the trivial dose range (a few tens of µSv per incident).
- The doses which may result from particle contamination may generally be higher. In rare cases the doses may exceed the trivial range, doses of a few mSv (per incident) cannot be excluded.

In conclusion, the analysis has shown that especially particle contamination needs to be focussed on. However, by the advanced detection equipment in German plants doses which may pose a health hazard can safely be excluded.

1. Introduction

In very rare cases the contamination of private clothing of persons leaving the controlled area of a nuclear installation may not be detected. Thereby radiological consequences for this person and the members of the family may occur. A radiological calculation was carried out by Brenk Systemplanung GmbH (Aachen/Germany), taking into account different aspects like source terms, nuclide vectors, pathways leading to contamination and exposure scenarios. The dose rates are calculated with deterministic and probabilistic models and the results are compared.

This paper relates to the paper “Radioactive Contamination on Private Clothing” of Manfred Meyer of Kernkraftwerk Philippsburg.

2. Source Terms for Contamination on Private Clothing

2.1. Contamination Mechanism

A thorough evaluation of possible pathways by which activity on clothing may eventually be transferred from the controlled area to a place outside has been performed by the German power utilities and has revealed the following main possible pathways:

- material lock: from material which is brought out of the controlled area part of the contamination may be transferred to persons, other material, vehicles.
- exit of the controlled area: a particle or surface contamination may remain on the body of the person leaving the controlled area. This contamination may be hidden on a part of the body where it is shielded and not detected by the person monitor.
- small objects: small items which a person takes out of the controlled area may bear some contamination which is not detected in the gate monitor.

2.2. Types of Contamination and Source Term

In order to develop a radiological model, it is important to take into account the different nature of types of contamination which may be present on private clothing. Contamination may have the form of particles or of surface contamination. In the first case, the contamination is very localised and may be transferred only in the form of the entire particle, in the latter case it is distributed over a larger area of the clothing and may be transferred in part or in total. Both types of contamination have been taken into account in the radiological assessment.

2.2.1. Particle Contamination

Particles are small pieces of matter which are highly insoluble and which possess a comparatively high specific activity. They may be transferred only intact and do not stick firmly to the clothing. Instead, they may fall off and be transferred to other places where they could lead to exposure. On the other hand, they may stick e.g. in pockets, pleats or seams of garments for longer times than surficial contamination which is totally dissolved when being washed.

Particles with a high Co 60 activity often originate from steels with high Co contents. Radioactive decay leads to electrical charging of the particles making them highly mobile. This is accounted for in the radiological scenarios.

For the assessment it is assumed that particles will contain maximum activities of 50 kBq Co 60. No case of particle contamination in German NPPs with activities of more than 5 kBq Co 60 has been reported. However, in order to be enveloping, a maximum activity of one order of magnitude higher has been assumed.

Those particles described here are generally too large to be inhaled. On the basis of a density of 3.5 g/cm³ and specific activities in the range between 10^7 and 10^9 Bq/g, diameters in the range of 70 µm for 5 kBq and 320 µm for 50 kBq are calculated whereas particles are inhalable only with diamters of less than about 20 µm.

2.2.2. Surface Contamination

Surface contamination is regarded here as a more or less homogeneous contamination on the clothing which is distributed over several 100 cm². The contamination mechanism will usually involve contaminated liquids or greasy contaminated material surfaces with which the piece of clothing has come into contact. Part of the surface contamination can be transferred to the skin or be incorporated.

For the radiological assessment, an activity of 5 kBq Co 60 has been chosen. It has been assumed that the contamination is distributed over 400 cm².

2.3. Nuclide Vectors

The radiological assessment (section 3) has been carried out individually for a number of nuclides which might be present in NPPs as well as for typical nuclide vectors. For the sake of space, only the results for Co 60 and for 2 typical nuclide vectors are reported in this paper (table 1). NV1 consists only of the most important β/γ emitting nuclides Co 60 and Cs 137 while NV2 is more representative for the actual contamination composition including around 1% of á emitting nuclides as well as pure β emitters.

Table 1: Nuclide vectors for the radiological assessment

Nu-clide	Co 60	Ni 63	Zn 65	Sr 90	Cs 137	Eu 154	Pu 238	Pu 239	Pu 240	Pu 241	Am 241	Cm 242	Cm 243	Cm 244
NV1	50%				50%									
NV2	40%	4%	10%	5%	30%	10%	0.1%	0.1%	0.1%	0.3%	0.1%	0.1%	0.1%	0.1%

3. <u>The Radiological Assessment</u>

3.1. Basic Approach

The radiological assessment was carried out in the following steps:

1. Pathways leading to contamination of private clothing (section 2.1);
2. Source term and nuclide vectors (section 2.2 and 2.3);
3. Exposure scenarios (section 3.2) and
4. Dose calculation (section 4).

The main part of the assessment was carried out using deterministic scenarios, i.e. scenarios with a fixed set of parameter values describing enveloping exposure situations. The results of such an assessment are doses which are highly unlikely to underestimate the exposure in the given circumstances. In order to get a more realistic assessment, a probabilistic assessment was also carried out. In this case, parameter values are left to vary according to predetermined statistical distributions and between upper and lower boundaries thus representing variation in real-life situations. Probabilistic analyses can help to assess the probability with which the conservative estimates of the deterministic assessment might occur.

3.2. Description of Scenarios

Radiological scenarios establish the link between the activity and the resulting dose. A number of scenarios have been chosen to describe situations in which a person is exposed by particle or surface contamination, taking the various transfer mechanisms into account. Where appropriate, the age groups according to ICRP are considered: 0-1 a, 1-2 a, 2-7 a, 7-12 a, 12-17 a and > 17 a (adults). The dose evaluation is performed for all age groups and the maximum value is taken.

3.2.1. Scenarios for Surface Contamination

A1: contamination on a jacket over 400 cm². The jacket is worn for 30 days for 5 h each day.

A2: initial contamination on the hand of a person. 5 % of this contamination is inadvertantly ingested. The rest remains on the hand for 24 h until being washed off (skin contamination).

A3: surface contamination is transferred to the private clothing of a person while being on the site of a nuclear power plant (outside controlled area). At home, this person is in contact with a small child which inadvertantly ingests 50% of this contamination.

A4: initial contamination on the hand of a person. At home, 50% of this contamination is transferred to an item (e.g. curtain) in the sleeping room where it remains for 1 a and leads to external irradiation.

3.2.2. Scenarios for Particle Contamination

B1: particle on/in a jacket. The jacket is worn for 60 days for 5 h each day.

B2: particle contamination is transferred to the private clothing or the shoes of a person. At home, this particle is transferred to the hands and is then inadvertantly ingested.

B3: particle contamination is transferred to the private clothing of a person while being on the site of a nuclear power plant (outside controlled area). At home, this particle is transferred to a piece of furniture where it remains for 1 month and leads to external irradiation.

B4: particle contamination on a small private object, e.g. spectacles or watch. This object is assumed to be worn 16 h per day. The particle remains for 1 month and then falls off.

4. Results

4.1. Dose Calculations

The results of the dose calculations are presented for Co 60 (table 2) and the two nuclide vectors presented in section 2.3 (table 3 and table 4). All calculations refer to 5 kBq for surface contamination and 50 kBq for particle contamination. This activity relates to γ emitting nuclides.

Table 2: Dose calculations for Co 60

Surface Contamination					
Parameter	**Scenario:**	**A1**	**A2**	**A3**	**A4**
(critical) age group		>17a	12-17a	1-2a	<1 a
dose from external irradiation	µSv	63,75	10,20	0,00	0,42
dose from skin contam., effect. dose	µSv	0,02	0,06	0,00	0,00
dose from ingestion	µSv	0,00	3,95	67,50	0,00
sum of doses	**µSv**	**63,8**	**14,2**	**67,5**	**0,4**
Particle Contamination					
Parameter	**Scenario:**	**B1**	**B2**	**B3**	**B4**
(critical) age group		12-17a	1-2a	<1 a	>17a
dose from external irradiation	µSv	2136,00	0,00	3,32	797,44
dose from ingestion	µSv	395,00	1350,00	0,00	0,00
sum of doses	**µSv**	**2531**	**1350**	**3,3**	**172**

Table 3: Dose calculations for NV1

Surface Contamination					
Parameter	**Scenario:**	**A1**	**A2**	**A3**	**A4**
(critical) age group		>17a	12-17a	1-2a	<1 a
dose from external irradiation	µSv	39,38	6,30	0,00	0,26
dose from skin contam., effect. dose	µSv	0,02	0,07	0,00	0,00
dose from ingestion	µSv	0,00	5,23	48,75	0,00
sum of doses	**µSv**	**39,4**	**11,6**	**48,8**	**0,3**
Particle Contamination					
Parameter	**Scenario:**	**B1**	**B2**	**B3**	**B4**
(critical) age group		12-17a	1-2a	<1 a	>17a
dose from external irradiation	µSv	1344,00	0,00	2,09	501,76
dose from ingestion	µSv	522,50	975,00	0,00	0,00
sum of doses	**µSv**	**1867**	**975**	**2,1**	**108**

Table 4: Dose calculations for NV2

Surface Contamination					
Parameter	**Scenario:**	**A1**	**A2**	**A3**	**A4**
(critical) age group		>17a	12-17a	1-2a	<1 a
dose from external irradiation	µSv	34,82	5,57	0,00	0,23
dose from skin contam., effect. dose	µSv	0,02	0,06	0,00	0,00
dose from ingestion	µSv	0,00	6,56	60,52	0,00
sum of doses	**µSv**	**34,8**	**12,2**	**60,5**	**0,2**
Particle Contamination					
Parameter	**Scenario:**	**B1**	**B2**	**B3**	**B4**
(critical) age group		12-17a	1-2a	<1 a	>17a
dose from external irradiation	µSv	1186,76	0,00	1,85	443,06
dose from ingestion	µSv	656,08	1210,34	0,00	0,00
sum of doses	**µSv**	**1843**	**1210**	**1,8**	**95,6**

As can be seen from table 3 and table 4, the results are largely dependent on the strong γ emittiers because external irradiation will play the most important role in all scenarios (for nuclide vectors which are typical for NPPs). The results do not differ significantly between NV1 and NV2. Furthermore, a comparison with table 2 reveals that it is obviously an enveloping approach to attribute the entire contamination to Co 60 which indeed has been found to be the most important nuclide in real contamination events.

4.2. Comparison with Dose Criteria

The results obtained in section 4.1 have to be judged against dose criteria. Possible dose criteria are:

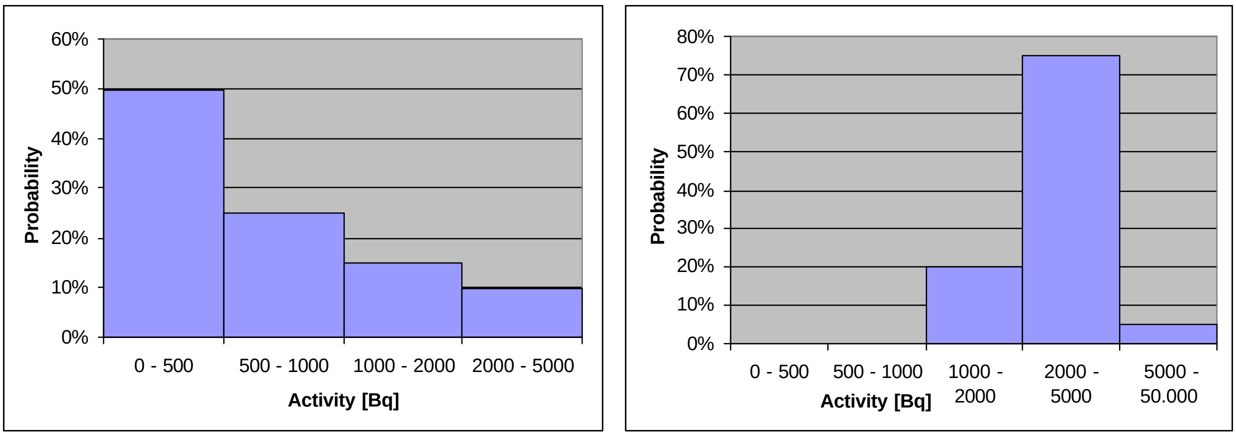
- the range 10 to 100 µSv which is usually regarded as the trivial dose range. Doses not exceeding this range could be regarded as negligible.
- 1 mSv: 1 mSv/a is the annual dose limit for members of the general public from practices according to the Basic Safety Standards of the European Union and of the IAEA. Doses in this range (from one single incident of contamination of private clothing) could therefore be regarded as acceptable if it is highly unlikely that several incidents per year might occur for the same person.
- 6 mSv/a / 20 mSv/a: these dose levels apply to controlled workers and are therefore not applicable to exposure situations of members of the general public.

The result of the radiological assessment shows that any dose which could reasonably be expected from a single incident lies below around 100 µSv for surface contamination and up to about 2 mSv for particle contamination. That means that surface contamination will in any case lead to only negligible doses while particle contamination has the potential also for doses beyond the trivial range. This result, must be judged in light of the fact that up to now only particles with a tenth of the activity which has been assumed here have been detected. Therefore, it is highly unlikely that also in the case of particle contamination on private clothing in Germany doses have been above the 100 µSv range.

4.3. Additional Probabilistic Assessment

As mentioned in section 3.1, a probabilistic assessment has also been carried out in which the most important parameter values were allowed to vary according to predetermined statistical distributions. From actual cases, the probability distributions for the activity in the case of surface contamination and of particle contamination shown in figure 1 have been derived.

Figure 1: Probability distribution for the activity for surface and particle contamination



Other parameters allowed to vary were:

- the probability that a child would be affected at all in scenarios A3 and B2 according to German demographical data;
- the time a garment is worn;
- transfer factor to the skin or to curtain/furniture;
- transfer factor of surface activity being inadvertently ingested;
- distance to the source (for calculation of external irradiation)
- and others.

Typical results for scenarios A3 and B1 for Co 60 are shown in figure 2. It can be seen e.g. for scenario B1 that it can be expected that the most probable doses will not be in the range of 2 mSv as calculated in the deterministic approach but may rather lie in the range of a few 100 µSv. The statistical data for the results are given in table 5.

Figure 2: Results of probabilistic dose calculations for Co 60 for scenarios A3 and B1 (note: different ranges on abscissa)

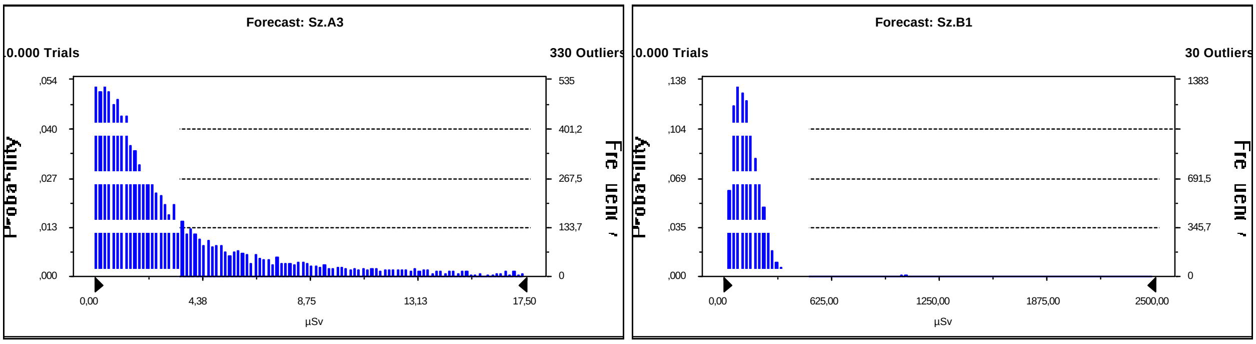


Table 5: Statistical data for the probability distribution of the doses for scenarios A3 and B1 for Co 60

Percentile	Scenario B3 [µSv]	Scenario B1 [µSv]
50% (Median)	2,01	133,86
95%	14,28	359,66
97,5%	19,48	1110,84
Maximum	53,62	3903,40
Comparison deterministic	67,5	2531

5. Conclusions

The comparison of the deterministic and probabilistic calculation methods reveals the following aspects:

- The deterministic calculations or results are obviously conservative compared to the probabilistic calculations.

- The effective doses, which will occure in reality because of a contamination of private clothes (probabilistic calculations) are around one order of magnitude smaller than the deterministically determined doses.

- It is very improbable that in case of surface contamination the effective dose will reach the trivial dose range of a few 10 µSv up to 100 µSv. But in cases of particle contamination effective doses of a few 100 µSv (95%-percentile) or up to the mSv-range (97,5%-percentile) can be reached.

That means that surface contamination will in any case lead to only negligible doses. In case of particle contamination it is highly unlikely that contamination on private clothing in Germany has effected doses exceeding the 100 µSv range.

In conclusion, the analysis has shown that especially particle contamination needs to be focussed on. However, by the advanced detection equipment in German plants doses which may pose a health hazard can safely be excluded.