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Significance of the results from probabilistic safety assessment at level 2 for off-site consequences

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VTT Energy

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ABSTRACT

The procedure was developed to enable STUK to make simplified estimates on off-site consequences based on the existing results of the PSA level 2 calculations done by e.g. power utilities. Method is based on dose calculated from each nuclide group of reactor activity inventory when the same release fraction for each group is assumed.

This means that a specific new result from PSA level 2 can be categorised to find out a representative PSA level 3 result for this case. In addition a user interface including the procedure was prepared. Secondly some new insights about consequences based on the releases from PSA level 2 is expected to give better understanding of risks at prevailing increased reactor power levels. In this case only some early health effects and long-term doses were estimated without full-scope PSA level 3 approach.

CONTENTS

1 INTRODUCTION

This study is composed of two parts. First a procedure was developed to enable STUK to make simplified estimates on off-site consequences based on the existing results of the PSA level 2 calculations performed by e.g. power utilities. This means that a specific new result from PSA level 2 can be categorised to find out a representative PSA level 3 result for this case. The presumption is that there are lot of precalculated off-site consequence cases covering the whole spectrum of new releases. Secondly some new insights about consequences based on the releases from PSA level 2 is expected to give better understanding of risks at prevailing increased reactor power levels. In this case only some early health effects and long-term doses were estimated in selected plant damage states without full-scope PSA level 3 approach.

2 SIMPLIFIED METHOD FOR CLASSIFICATION OF SOURCE TERMS

The simplified method is based on dose calculated from each nuclide group of reactor activity inventory assuming the same release fraction for each group. Due to nuclide specific halflifes both short-term dose as well as long-term dose are calculated to indicate possible significance of different nuclide groups for categorisation. The reactor core inventories of Loviisa and Olkiluoto are based on the results from ORIGEN 2 and inventory values at the end of loading period in steady state conditions are used. The inventories are shown in appendices 1 and 2. Dispersion in the air is calculated on the basis of annual weather statistics for the sites. This statistics includes probability of dispersion in 12 sectors, in 6 stability classes, in 7 wind speed classes and rain occurrence.

Dose is considered here as an expected individual dose aggregated over the distance intervals employed. This approach of an individual risk was chosen because utilisation of real population data might cause uncertain result due to sparsely populated areas at short distances from the power plants. Therefore results are relative and intended only for classification method of source terms but not for calculation of absolute dose values. The dose is calculated here as an expected value, which includes wide spectrum of single dose values due to different dispersion conditions. If we consider the possibility to utilise this method in emergency preparedness, we should notice that then there is probably only one well defined dispersion condition. In addition results cannot be converted to absolute values e.g. acute health effects due to the assumptions done in calculations and threshold type behaviour of early health effects.

Short-term dose (Dose_Short) is integrated to 1 month as a bone marrow dose at several distances up to 10 km, because acute health effects are assumed to occur in this interval. Exposure pathways are cloudshine, inhalation and groundshine.

Long-term dose (Dose_Long) is integrated to 50 years as an effective dose at several distances up to 100 km, because number of late health effects is based on total dose. Exposure pathways are cloudshine, inhalation and groundshine. Ingestion dose has been excluded from the calculations of this study.

Release start time after shutdown may affect the radioactive decay of nuclides and therefore four delay times for the release onset (0 h, 24 h, 120 h and 336 h) were studied. The value of 3 hours was used as a release duration in all cases of the classification part, which is also taken into account in horizontal dilution factor as well as in the nuclide specific decay chains. Then both of Dose_Short and Dose_Long were calculated from each nuclide group employing the ARANO computer code [1] and the results were tabulated according to nuclide groups and release start times. All the nuclide group specific results are normalised to the results obtained for caesium at the first release delay case i.e. to value of 1. In the case of Olkiluoto only results for the release altitude of 100 m were reported. In the case of Loviisa three release altitudes, 60, 20 and 0 m, were reported. Results are shown in Table I (Olkiluoto) and Table II (Loviisa) and in derived Figures 1...4.

In calculations the release altitude of 100 m was used as a reference release altitude. For Olkiluoto releases this is also the only release altitude but for Loviisa releases the altitude is dependent on the power plant damage state (PDS) and varies from 0 m to 60 m. Release altitude affects the weighting factors. In this method the lower release altitude results in higher scaling factor. If interrelation of the nuclide groups at each release altitude is compared, one can see that all the other groups but noble gases behave similarly.

Table I. *Nuclide group specific factors indicating importance of each group in short-term and long-term dose from the Olkiluoto reactor. Results are based on calculation in which the same fraction of each nuclide group is released and annual weather statistics of the site is used to weight different dispersion conditions to calculate the expected value of dose for the considered release case. Results are normalised to the result caused by caesium isotopes in the first delay case. Release altitude is 100 m.*

Delay time	Noble gases	Iodine	Caesium	Tellurium	Strontium	Ruthenium	Lantanides
Dose_Short							
0 h	0.039	1.1	1	1.5	0.72	2.2	10.3
24 h	0.0041	0.56	0.98	1.2	0.63	2.1	9.3
5 days	0.00088	0.31	0.97	0.51	0.52	1.9	7.6
14 days	0.00019	0.13	0.96	0.082	0.36	1.5	6.6
Dose_Long							
0 h	0.001	0.049	1	0.044	0.068	0.28	1.9
24 h	0.00011	0.032	1	0.035	0.066	0.28	1.9
5 days	0.000024	0.019	1	0.016	0.062	0.26	1.8
14 days	$7.4 \cdot 10^{-6}$	0.0083	1	0.0028	0.056	0.25	1.7

Nuclide groups consist of:

Noble gases: Xe, Kr; Iodine: I; Caesium: Cs, Rb; Tellurium: Te, Sb; Strontium: Sr, Ba; Ruthenium: Ru, Rh, Co, Mo, Tc; Lantanides: La, Y, Zn, Nb, Ce, Pr, Nd, Np, Pu, Am, Cm

Distance intervals employed [km]

Dose_Short: 1–2, 2–3, 3–4, 4–5, 5–7.5, 7.5–10,

Dose_Long: 1–2, 2–3, 3–4, 4–5, 5–7.5, 7.5–10, 10–12.5, 12.5–15, 15–20, 20–30, 30–40, 40–60, 60–80, 80–100

Effect of release duration is illustrated in Figure 5 for the groups: noble gases, iodine and tellurium when 8 hours and 24 hours as well as 3 hours as a reference value are used. Here only decay but not increased horizontal dispersion is considered. Column bars are short-term doses representing 3 different delay times for a release. Figure 5 indicates that if the release starts immediately after shutdown the short-term dose from noble gases is reduced by a factor of 1.5 for 8 hour release and by a factor of 3 for 24 hour release when compared to 3 hour release as a reference. For iodine group the corresponding values are 1.3 and 1.5 and for tellurium group ~ 1 and 1.1, respectively. If the release onset is delayed the effect of release duration on dose reduction is decreased.

Finally the PSA2 releases were classified with the program in which the input consists of the tabulated weighting factors as presented in Tables I and II as well as of the tables including nuclide group specific release fraction and start time of the release after shutdown [2, 3]. In the case of Olkiluoto the time was given in the same table but in the case of Loviisa the release time as well as the release altitude had to be extracted from separate files. Then the values for Dose_Short and Dose_Long were interpolated for the time point representing the release onset and finally the severity factor for each release bin was calculated as defined in equations 1 and 2.

$$\text{Bin\_severity\_Short} = \sum_{i=1}^{n} [\text{Dose\_Short}(h,\ t,\ i) \cdot \text{RF}(i)] \tag{1}$$

and

$$\text{Bin\_severity\_Long} = \sum_{i=1}^{n} [\text{Dose\_Long}(h,\ t,\ i) \cdot \text{RF}(i)] \tag{2}$$

where

i = index of nuclide group,
h = release altitude,
t = time of release onset,
RF = release fraction of nuclide group i.

Table II. *Nuclide group specific factors indicating importance of each group in short-term and long-term dose from the Loviisa reactor. Results are based on calculation in which the same fraction of each nuclide group is released and annual weather statistics of the site is used to weight different dispersion conditions to calculate the expected value of dose for the considered release case. Results are normalised to the results caused by caesium in the first delay case from the release altitude of 100 m.*

Delay time	Noble gases	Iodine	Caesium	Tellurium	Strontium	Ruthenium	Lantanides
Dose_Short							
100 m							
0 h	0.05	1.6	1	2.3	1.1	3.1	14.9
24 h	0.0049	0.83	0.95	1.9	0.96	2.9	13.4
5 days	0.0011	0.47	0.91	0.79	0.79	2.5	10.9
14 days	0.00034	0.2	0.86	0.13	0.54	2.1	9.5
60 m							
0 h	0.13	4.1	2.7	6.2	2.9	8.2	39.8
24 h	0.013	2.2	2.5	5.0	2.6	7.7	35.8
5 days	0.0030	1.3	2.4	2.2	2.2	6.8	29.1
14 days	0.00092	0.54	2.3	0.35	1.5	5.7	25.4
20 m							
0 h	0.20	10.6	7.3	17.4	8.2	22.7	110
24 h	0.021	5.9	7.1	14.0	7.2	21.6	100
5 days	0.0047	3.4	6.8	5.9	5.9	19.0	81
14 days	0.0014	1.5	6.4	0.97	4.1	15.9	71
Dose_Long							
100 m							
0 h	0.0015	0.085	1	0.082	0.097	0.39	2.4
24 h	0.00016	0.056	1	0.066	0.092	0.39	2.3
5 days	0.000035	0.033	0.99	0.028	0.085	0.37	2.2
14 days	0.000011	0.015	0.99	0.0053	0.074	0.34	2.1
60 m							
0 h	0.0039	0.22	2.6	0.21	0.25	1.0	6.2
24 h	0.0040	0.14	2.6	0.17	0.24	1.0	6.1
5 days	0.000093	0.086	2.6	0.074	0.22	0.96	5.7
14 days	0.000029	0.038	2.6	0.014	0.19	0.88	5.4
20 m							
0 h	0.0060	0.56	6.9	0.56	0.66	2.7	16.4
24 h	0.00061	0.37	6.9	0.45	0.63	2.6	16.0
5 days	0.00014	0.22	6.8	0.19	0.58	2.5	15.1
14 days	0.000044	0.10	6.8	0.036	0.51	2.3	14.2

Nuclide group construction and distance intervals are the same as in Table I.

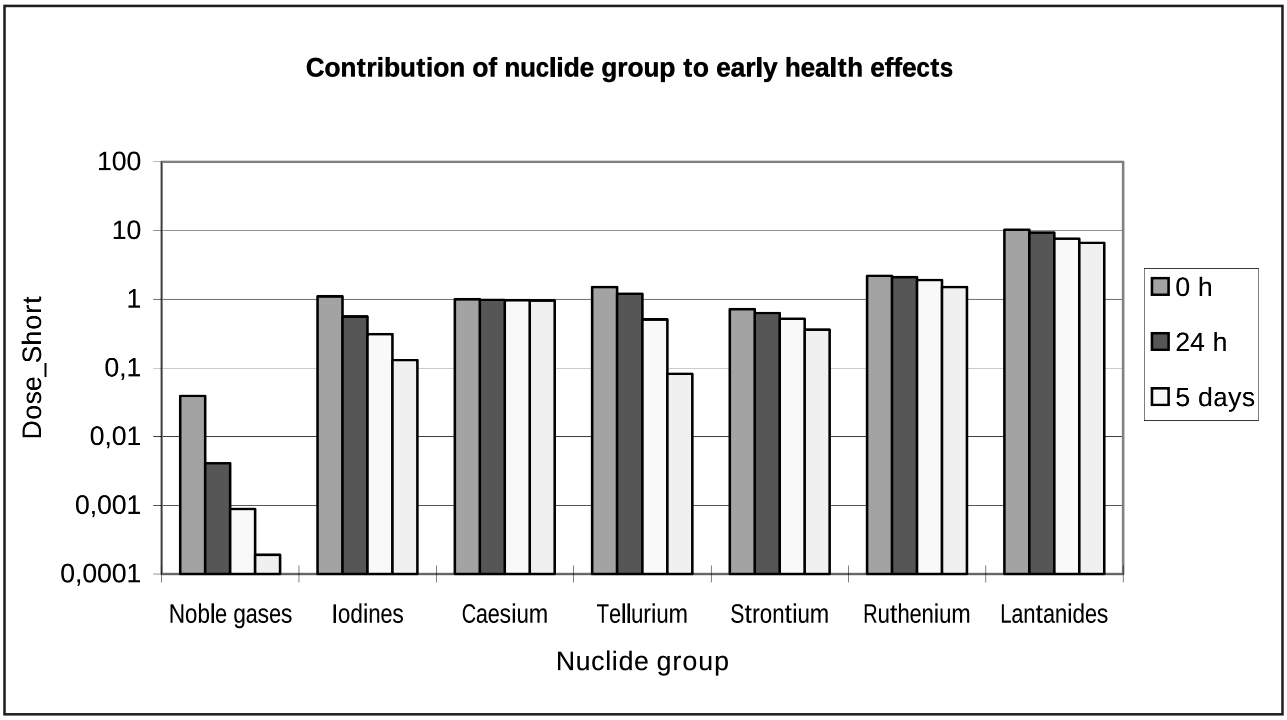


Fig. 1. *Significance of the nuclide group in the bone marrow dose integrated to 1 month. Values are normalised to caesium. The Olkiluoto core inventory and site specific weather data are used. Four delay times before the release are used.*

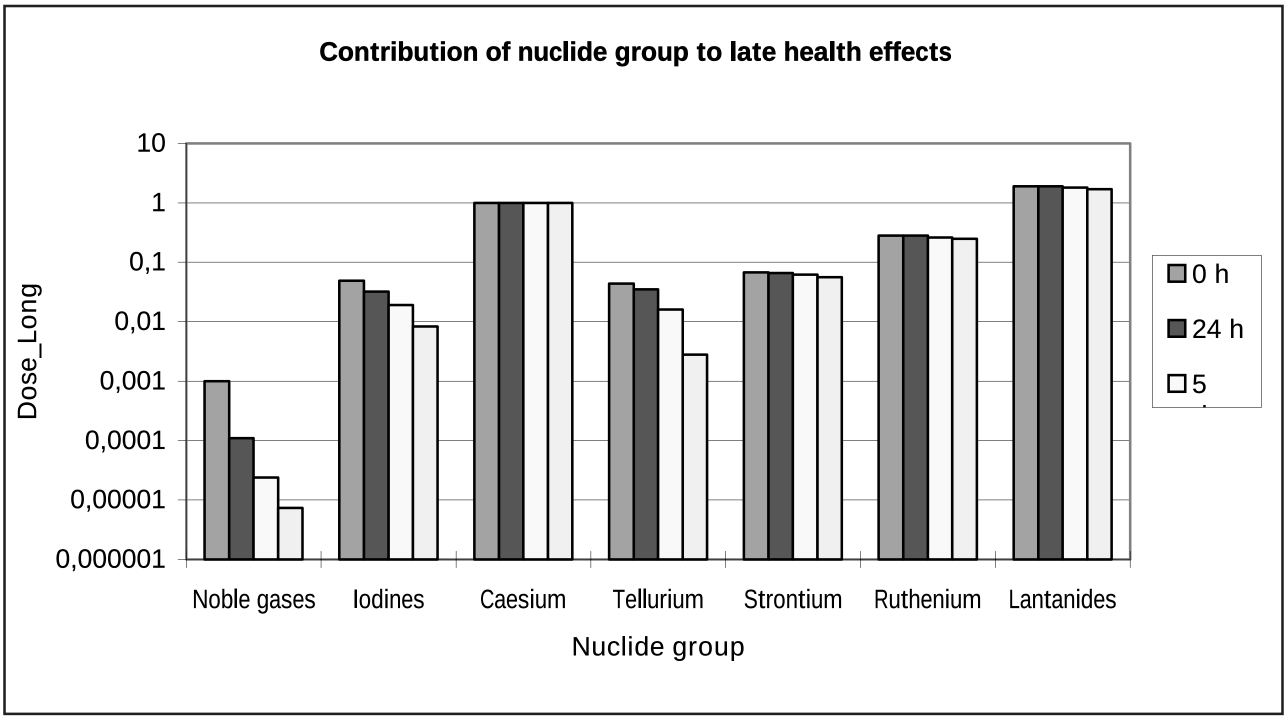


Fig. 2. *Significance of the nuclide group in the effective dose integrated to 50 years. Values are normalised to caesium. The Olkiluoto core inventory and site specific weather data are used. Four delay times before the release are used.*

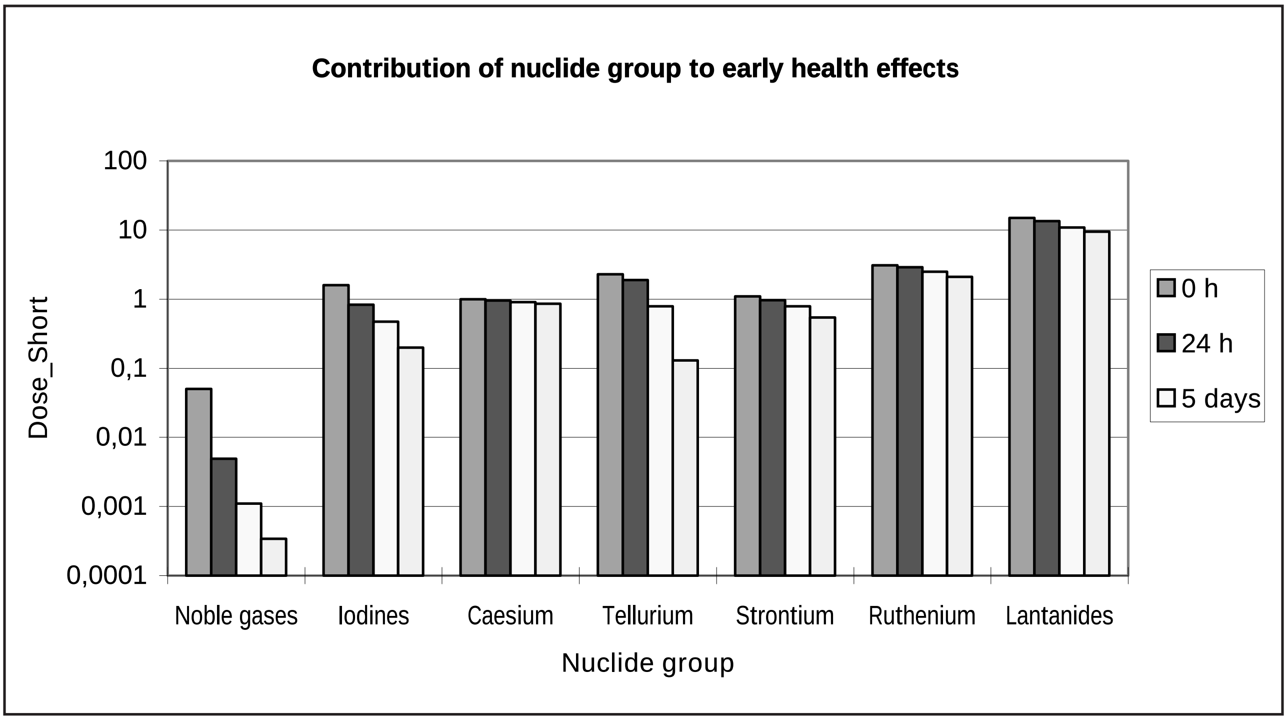


Fig. 3. *Significance of the nuclide group in the bone marrow dose integrated to 1 month. Values are normalised to caesium. The Loviisa core inventory and site specific weather data are used. Four delay times before the release are used. Release altitude is 100 m.*

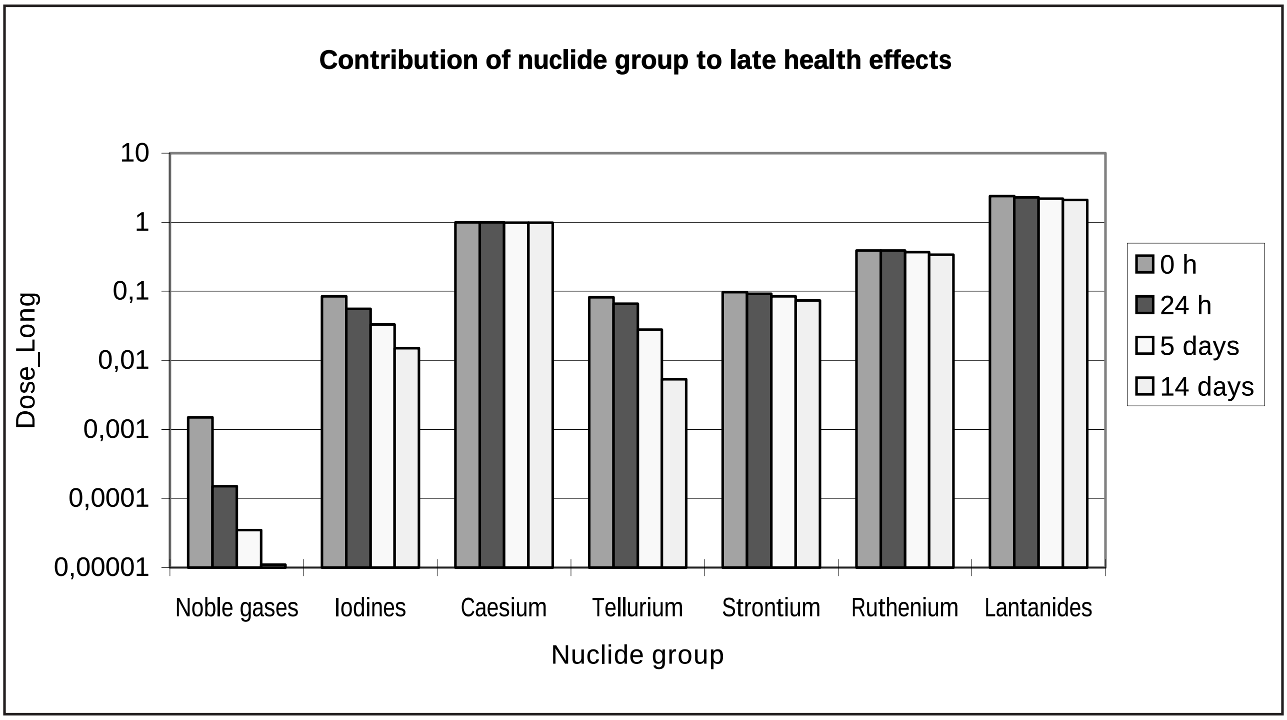


Fig. 4. *Significance of the nuclide group in the effective dose integrated to 50 years. Values are normalised to caesium. The Loviisa core inventory and site specific weather data are used. Four delay times before the release are used. Release altitude is 100 m.*

Results of this classification method are shown in Figure 6 for the Olkiluoto bins and in Figure 7 for the Loviisa PDS releases. Naming of the source terms is presented in appendices 3 and 4. Any new release category can be classified by multiplying nuclide group related release fraction with the site dependent coefficient provided in Table I or II. Some additional calculations indicate that it is possible to find a threshold value for Bin_Severity_Short above which early health effects appear. Here the amount of inhabitants exceeding a dose level of 1 Gy was calculated and the level when this value starts to exceed zero was looked for. In the case of Olkiluoto releases that value was found to be about $1{\cdot}10^{-2}$. Figure 6 indicates that nearly one third of the cases exceed this threshold value. If real population data were used the value of Bin_Severity_Short would obviously be reduced due to empty areas of inhabitants in the vicinity of the plant, but on the other hand densely populated areas further away would increase the value. For the Loviisa site no threshold value of early health effects was predicted in the present study.

Effect of the release start time after a reactor shutdown was investigated by calculating the results for the Loviisa power plant damage state (PDS) with two alternative delay times in all release cases. Figures 8 and 9 depict that in the case of short-term dose release onset has some minor influence on the dose. If the composition of a release were dominated by noble gases then result could be different but when release is composed from all nuclide groups then the significance of noble gases is lower. In the case of long-term dose the influence of release start time is insignificant. For both short-term and long-term dose estimates one has to take into account that the above conclusions apply to the normalised significance estimates and not to the absolute values.

Concerning PSA3 calculations it should be reminded that also frequency of the accident or more correctly that of release also affects the result. Frequency of the release can affect decisively the consequences because it can even nullify serious consequences or give larger weight on insignificant consequences.

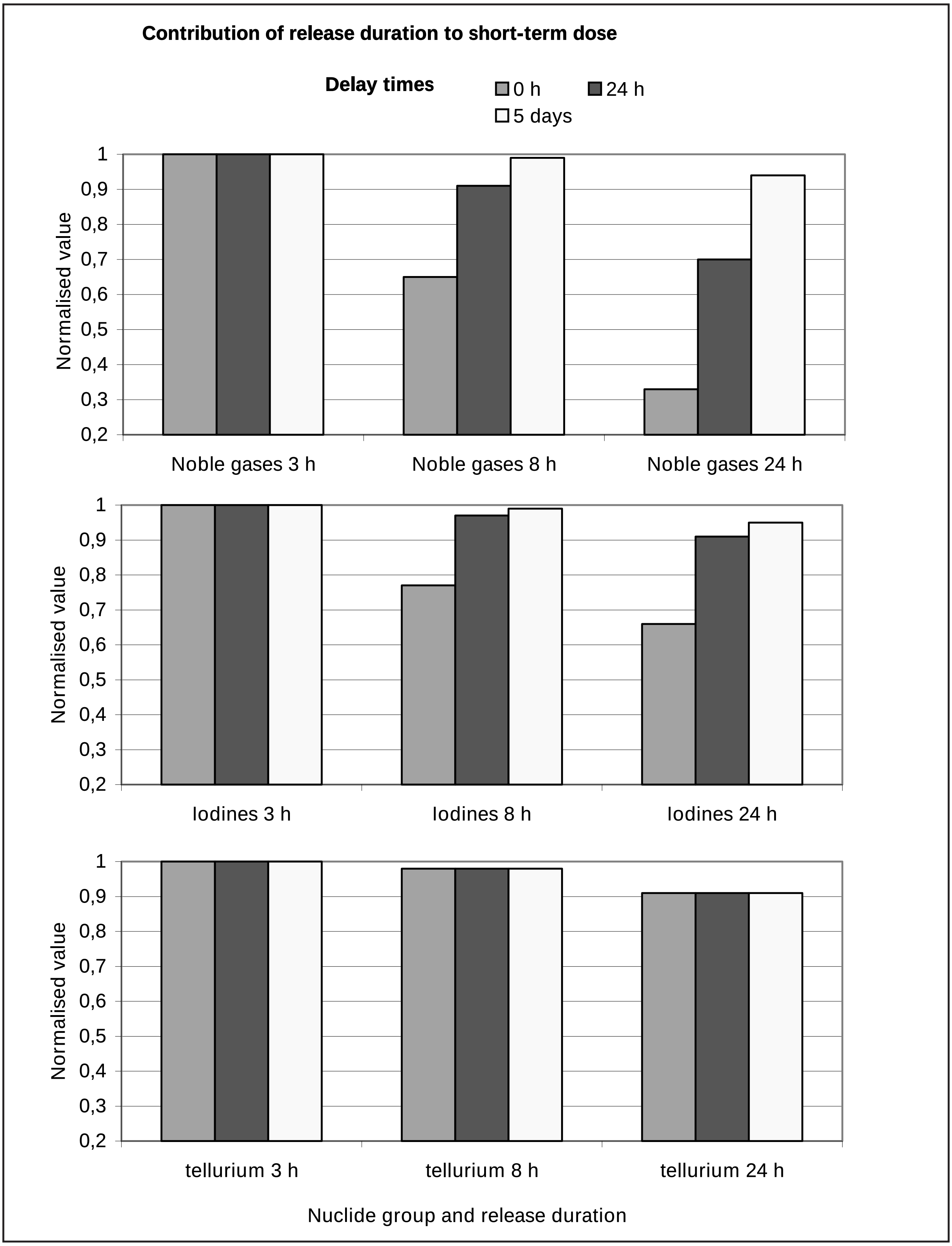


Fig. 5. *Significance of release duration when the start time of the release is varied. Bone marrow dose is integrated to 1 month. The Loviisa core inventory and site specific weather data are used. Three delay times before the release onset are used. Additional dispersion by increased duration is not considered. Values are normalised to 3 hour's release. Only column bars with the same colour shade should be compared in each figure.*

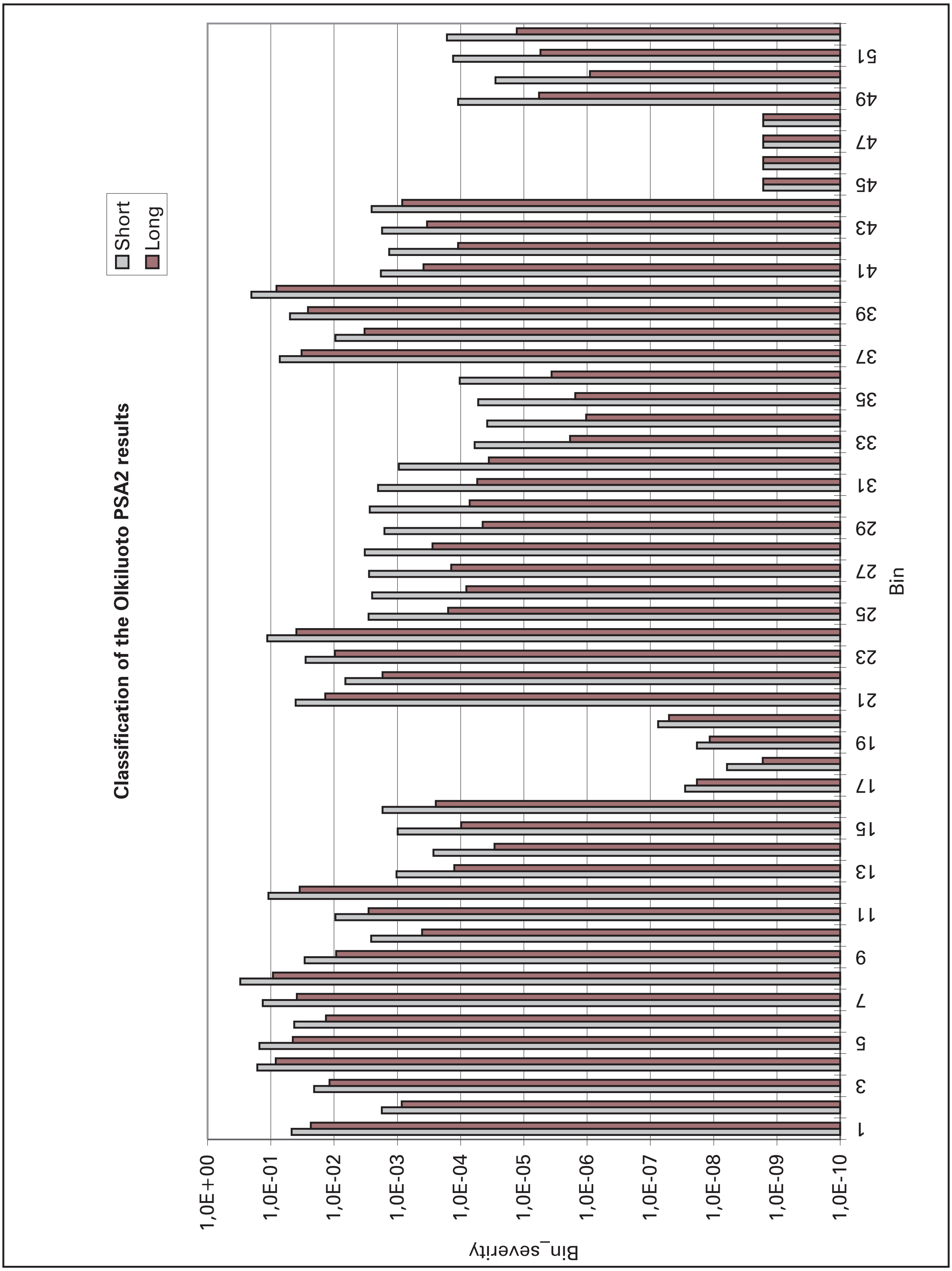


Fig. 6. *Classification of the Olkiluoto PSA2 results for offsite acute and late health effects. One bin includes 4 release cases. Column bar indicates relative significance of a release when the release frequency is excluded. Release duration is Assumed to be 3 hours in each case. The definitions of the bin numbers are given in Appendix 4.*

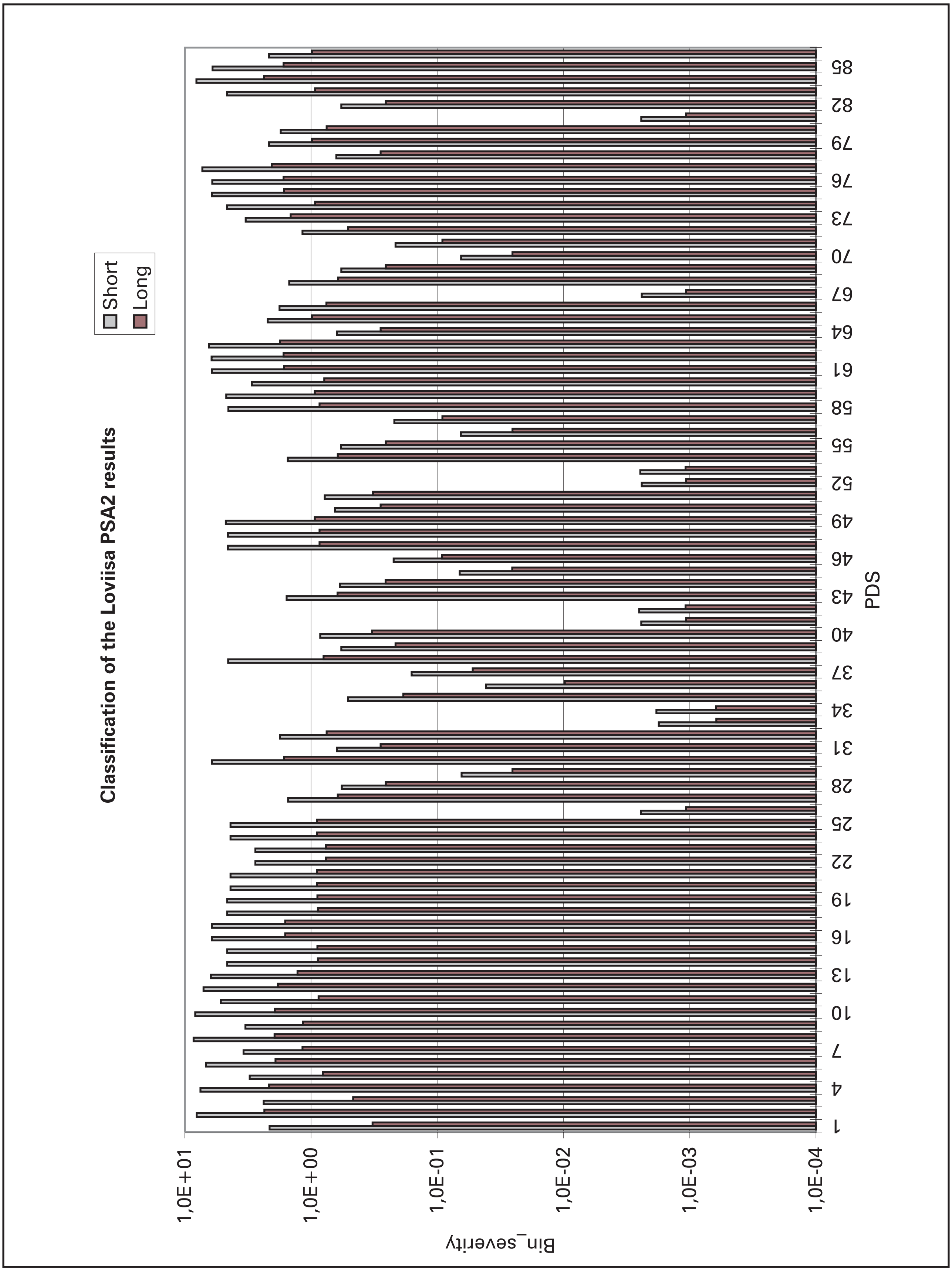


Fig. 7. *Classification of the Loviisa PSA2 results for offsite acute and late health effects. 86 release categories considered. Release altitudes were 60 or 20 meters. As a releases altitude for 0 meter was the value of 20 meters employed. Column bar indicates relative significance of a release when the release frequency is excluded. Release duration is assumed to be 3 hours in each case. The definitions of the plant damage state (PDS) numbering are given in Appendix 3.*

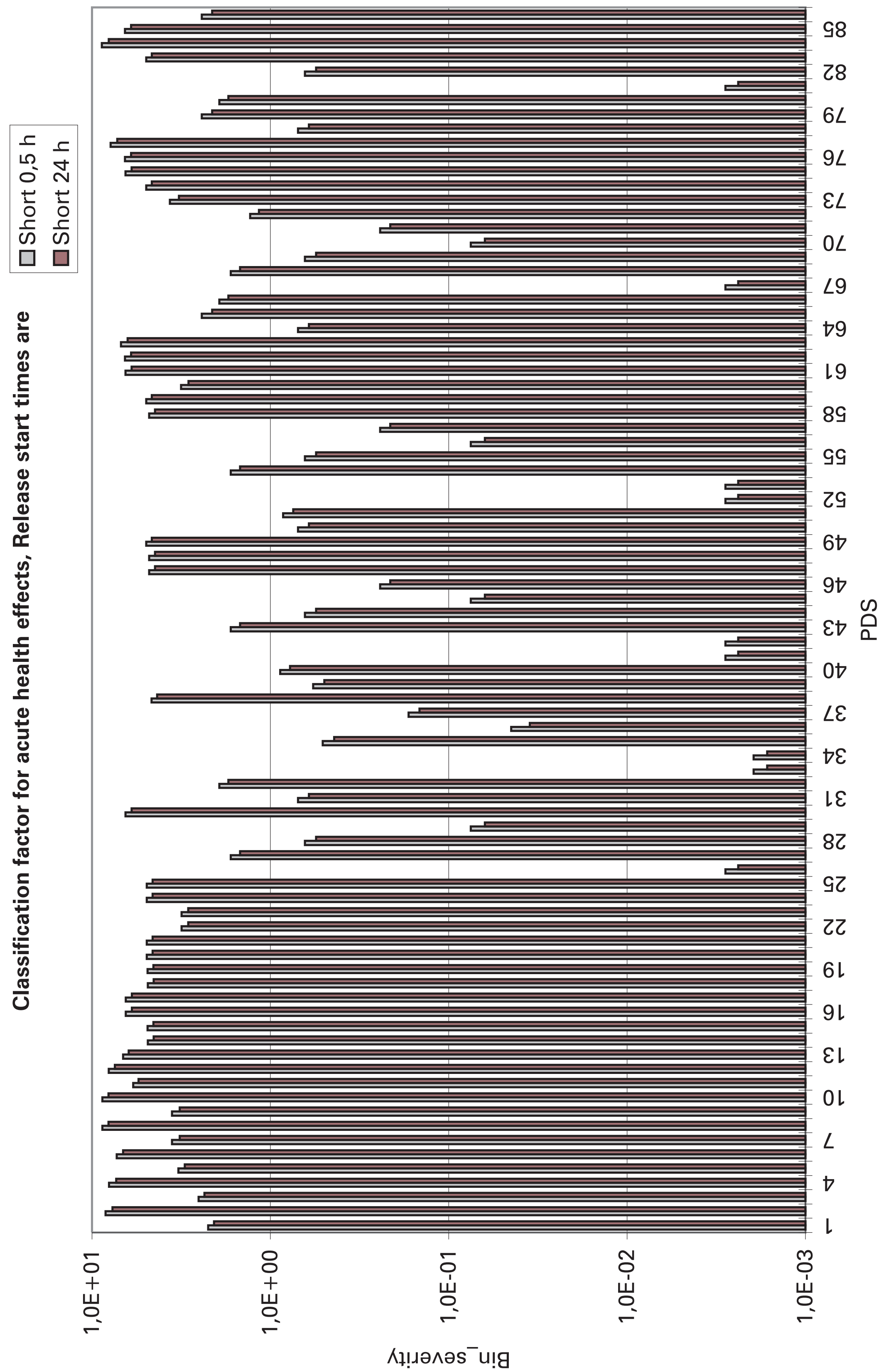


Fig. 8. *Effect of release start time on the Bin_severity of short term dose. Figure indicates the significance of release start time, when the release start times indicated in the legend are used instead of the reported start times the Loviisa PDS. Release duration is assumed to be 3 hours in each case. The definitions of the plant damage state (PDS) numbering are given in Appendix 3.*

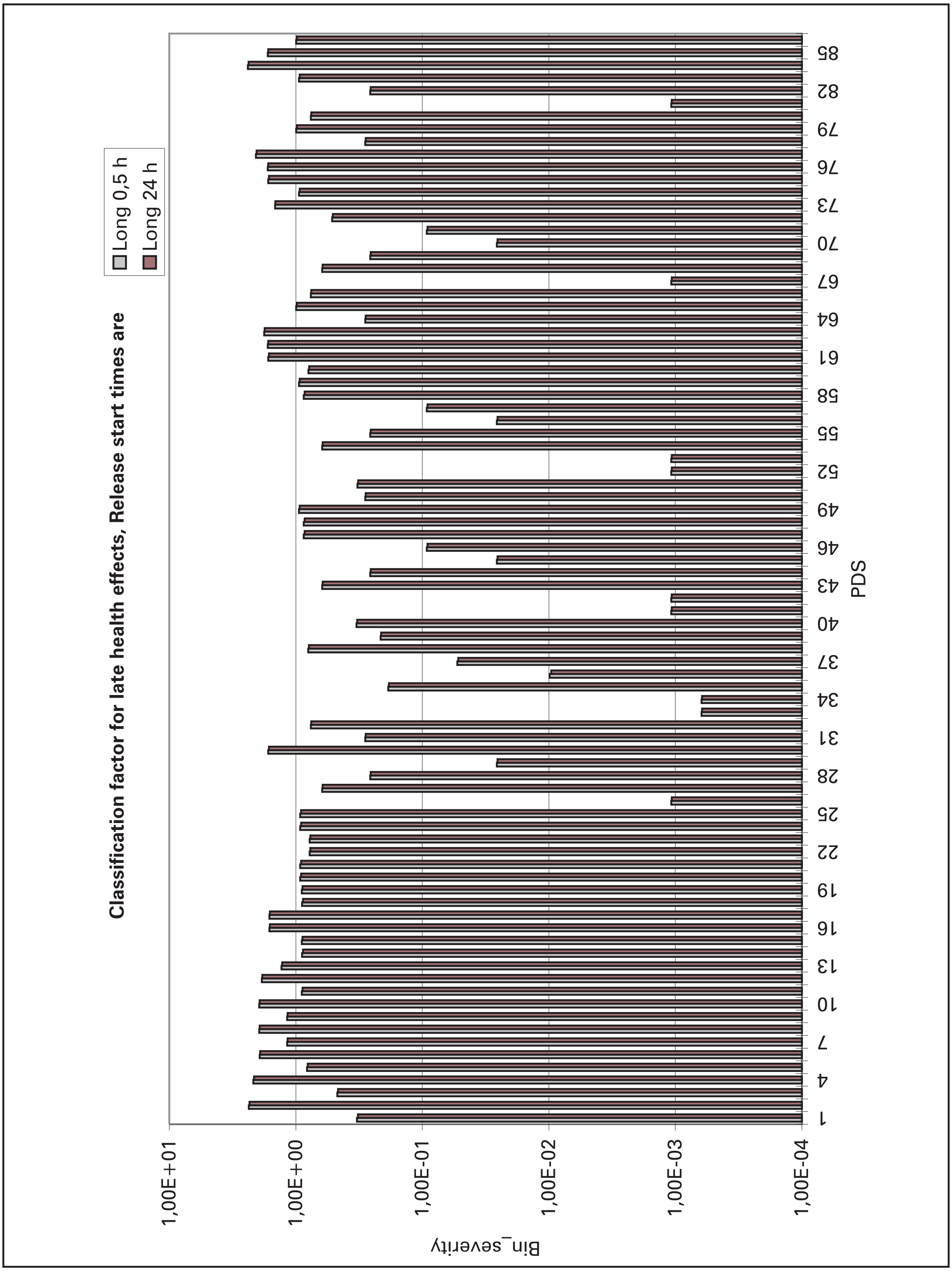


Fig. 9. *Effect of release start time on the Bin_severity of long term dose. Figure indicates the significance of release start time, when the release start times indicated in the legend are used instead of the reported start times for the Loviisa PDS. Release duration is assumed to be 3 hours in each case. The definitions of the plant damage state (PDS) numbering are given in Appendix 3.*

3 DOSE ESTIMATES FOR SELECTED RELEASES

A few release categories from the Loviisa and Olkiluoto PSA level 2 results were selected for off-site dose calculations. Here only acute health effects and long-term collective doses were considered. Source term data from the Loviisa power plant damage state (PDS) indicates multiphase behaviour, which is given as early, intermediate and late phase releases. Because of difficulties to handle all of these release periods separately, only one dominating phase with an assumption to include the whole amount of the release was employed in this study. The calculation results presented in this chapter have been derived directly with the computer code ARANO. Here absolute results with the site specific population distribution are presented rather than relative results as in chapter 2.

Acute health effects were calculated based on the bone marrow dose in 30 days when exposure pathways were cloudshine, inhalation and groundshine. Site specific weather and population data were used. About 10 years old population data was divided into two shielding groups, the first one (20 %) is assumed to stay outside and the second one (80 %) inside when the plume passes over. Otherwise population lives either normally or evacuation up to 10 kilometres is assumed to be carried out after 8 or 24 hours since the plume has reached it. Radiation illness cases are calculated using the threshold value of 1 Gy and the number of acute deaths is based on an assumption that the probability of death is increased from zero to one when bone marrow dose is increased from 2 Gy to 5 Gy.

The long-term (exposure time period from 0 to 50 years) effective collective dose was calculated from cloudshine, groundshine and inhalation assuming normal living conditions. Ingestion pathways were not considered. The source terms are presented in Tables III and IV. Timing of the release is taken from Table III and in the case of longer than 3 hour's release duration only decay but not increased horizontal dispersion is considered.

Table III. *Source term parameters in the dose calculations.*

Release *	Frequency [a^{-1}]	Start time from shutdown [h]	Release duration [h]	Release height [m]
NFL 95	$6.83 \cdot 10^{-7}$	1.79	3**	100**
VE_NCS 95	$3.38 \cdot 10^{-9}$	16.6	3**	100**
REFUEL 50	$3.60 \cdot 10^{-7}$	2.78	3**	100**
L_CF 95	$3.52 \cdot 10^{-9}$	13.2	3**	100**
BLTY APC6	$4.82 \cdot 10^{-7}$	8**	6**	20**
BLSY APC6	$5.70 \cdot 10^{-8}$	3**	5**	20**
NSIK APC22	$5.90 \cdot 10^{-9}$	7**	6**	60
NCRA APC1	$1.91 \cdot 10^{-6}$	13**	51**	60

* The acronyms refer to accident sequences (plant damage states) considered in PSA2—analyses for the Olkiluoto and Loviisa plants.

** Value estimated on the basis of the reports provided by the power utilities.

Table IV. Source terms as release fractions considered in the dose calculations.

Release	Noble gases	Iodine	Caesium	Tellurium	Strontium	Ruthenium	Lantanides
NFL 95	$5.91 \cdot 10^{-1}$	$9.01 \cdot 10^{-2}$	$7.86 \cdot 10^{-2}$	$9.08 \cdot 10^{-2}$	$2.63 \cdot 10^{-2}$	$2.54 \cdot 10^{-3}$	$2.78 \cdot 10^{-3}$
VE_NCS 95	$7.06 \cdot 10^{-1}$	$7.40 \cdot 10^{-2}$	$7.40 \cdot 10^{-2}$	$5.02 \cdot 10^{-2}$	$2.85 \cdot 10^{-2}$	$2.10 \cdot 10^{-3}$	$2.27 \cdot 10^{-4}$
REFUEL 50	$3.38 \cdot 10^{-1}$	$9.32 \cdot 10^{-3}$	$1.13 \cdot 10^{-2}$	$7.50 \cdot 10^{-4}$	$7.79 \cdot 10^{-4}$	$1.28 \cdot 10^{-5}$	$3.93 \cdot 10^{-6}$
L_CF 95	$6.31 \cdot 10^{-1}$	$1.90 \cdot 10^{-4}$	$1.92 \cdot 10^{-4}$	$4.04 \cdot 10^{-5}$	$7.16 \cdot 10^{-6}$	$2.79 \cdot 10^{-7}$	$3.68 \cdot 10^{-7}$
BLTY APC6	1.00	$3.26 \cdot 10^{-1}$	$2.51 \cdot 10^{-1}$	$1.62 \cdot 10^{-1}$	$1.05 \cdot 10^{-4}$	$2.61 \cdot 10^{-4}$	$1.33 \cdot 10^{-2}$
BLSY APC6	1.00	$3.45 \cdot 10^{-1}$	$2.76 \cdot 10^{-1}$	$1.66 \cdot 10^{-1}$	$1.37 \cdot 10^{-4}$	$2.61 \cdot 10^{-4}$	$1.33 \cdot 10^{-2}$
NSIK APC22	1.00	$4.74 \cdot 10^{-1}$	$3.48 \cdot 10^{-1}$	$3.82 \cdot 10^{-2}$	$6.10 \cdot 10^{-4}$	$3.50 \cdot 10^{-6}$	$9.37 \cdot 10^{-7}$
NCRA APC1	$8.63 \cdot 10^{-3}$	$4.62 \cdot 10^{-4}$	$3.70 \cdot 10^{-4}$	$6.47 \cdot 10^{-5}$	$1.87 \cdot 10^{-6}$	$1.04 \cdot 10^{-8}$	$2.75 \cdot 10^{-9}$

Nuclide groups consist of:

Noble gases: Xe, Kr; Iodine: I; Caesium: Cs, Rb; Tellurium: Te, Sb; Strontium: Sr, Ba; Ruthenium: Ru, Rh, Co, Mo, Tc; Lantanides: La, Y, Zn, Nb, Ce, Pr, Nd, Np, Pu, Am, Cm

Figures 10 and 11 illustrate the complementary cumulative distribution functions (CCDF) for acute health effects from the Olkiluoto releases NFL and VE_NCS given at 95 % confidence level. The CCDF curve indicates the probability of equalling or exceeding number of people suffering early health effects. The release frequency is included in results and thus the curves are below that probability level. Effect of evacuation is indicated in two figures below the figure describing normal living conditions assuming no countermeasures. Here no warning times were considered and in the case of NFL the release starts in 2 hours after shutdown so there is not much time to start evacuation before release. On the other hand in the case of VE_NCS the release starts 16 hours after shutdown and therefore in reality enough time would be available for evacuation before the release onset and then early health effects could be avoided.

Figures 12 and 13 illustrate the Loviisa PDS releases BLTY and NSIK, which start 8 and 7 hours after reactor shutdown. Thus it could be possible to evacuate population before the release onset. Figures 14 and 15 illustrate CCDF curves of the long-term collective doses for few different release cases and in normal living conditions. The corresponding expectation values are shown in Table V.

Significance of the release frequency on the risk can be found if we compare e.g. the cases NFL and VE_NCS of Table IV. From Figure 6 we can see that Bin_severities are almost equal for both of these releases. However, when two orders of magnitude higher frequency of the release NFL is aggregated into the risk, the results expressed in this way are totally different.

Table V. *Expectation values of the long-term collective doses. Exposure pathways are cloudshine, inhalation and groundshine. Release frequencies are given in Table III.*

Release category	Expectation value [manSv]
Olkiluoto NFL 95 %	$8 \cdot 10^{-3}$
Olkiluoto VE_NCS 95 %	$4 \cdot 10^{-5}$
Olkiluoto REFUEL 50 %	$6 \cdot 10^{-4}$
Olkiluoto L_CF 95 %	$1 \cdot 10^{-7}$
Loviisa BLTY APC 6	$2 \cdot 10^{-2}$
Loviisa BLSY APC 6	$2 \cdot 10^{-3}$
Loviisa NSIK APC 22	$3 \cdot 10^{-4}$
Loviisa NCRA APC 1	$9 \cdot 10^{-5}$

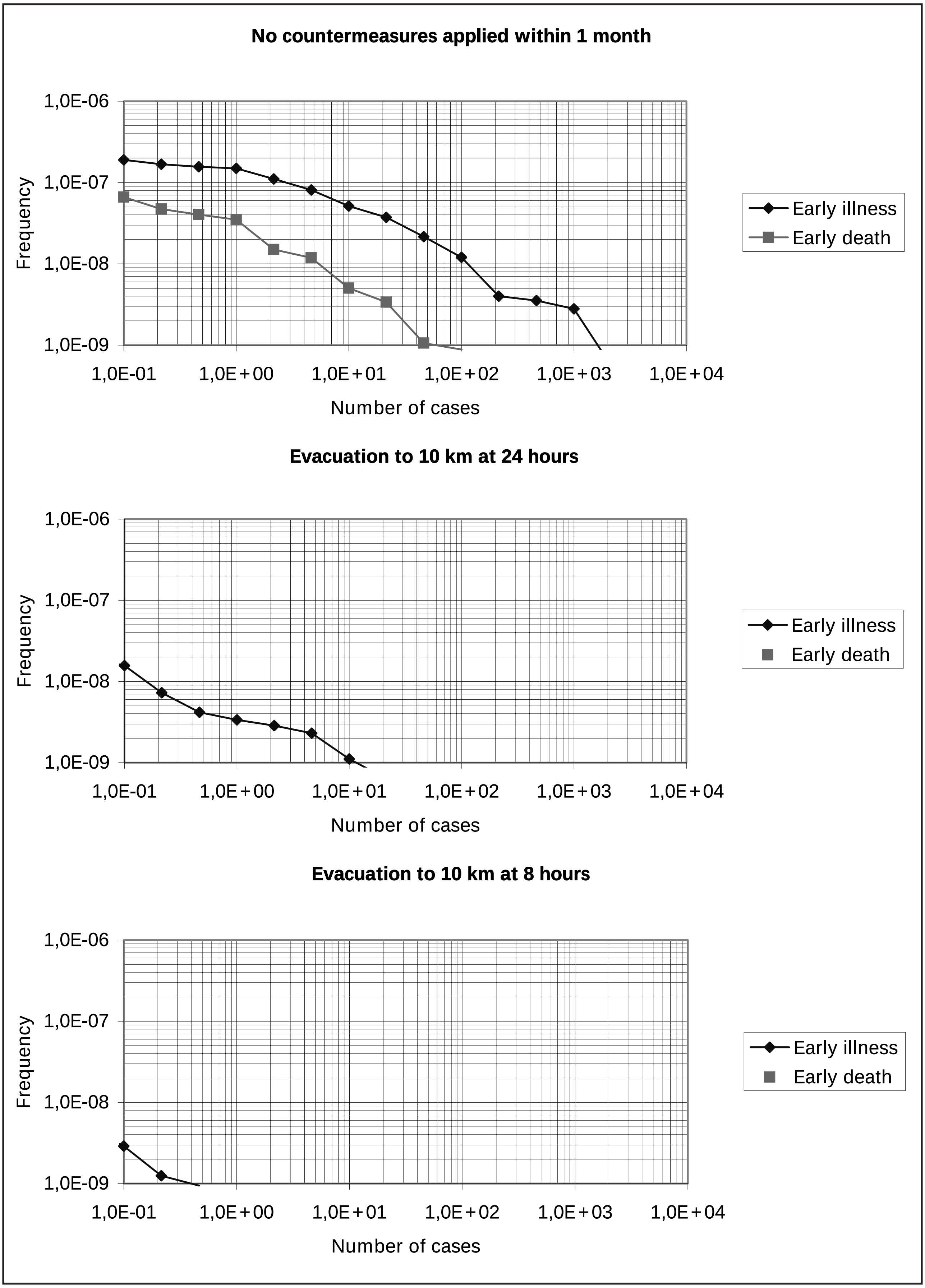


Fig. 10. *Early health effects from the Olkiluoto bin (NFL-95 %) in three alternative countermeasure schemes. Frequency of this bin is 6.83E-7.*

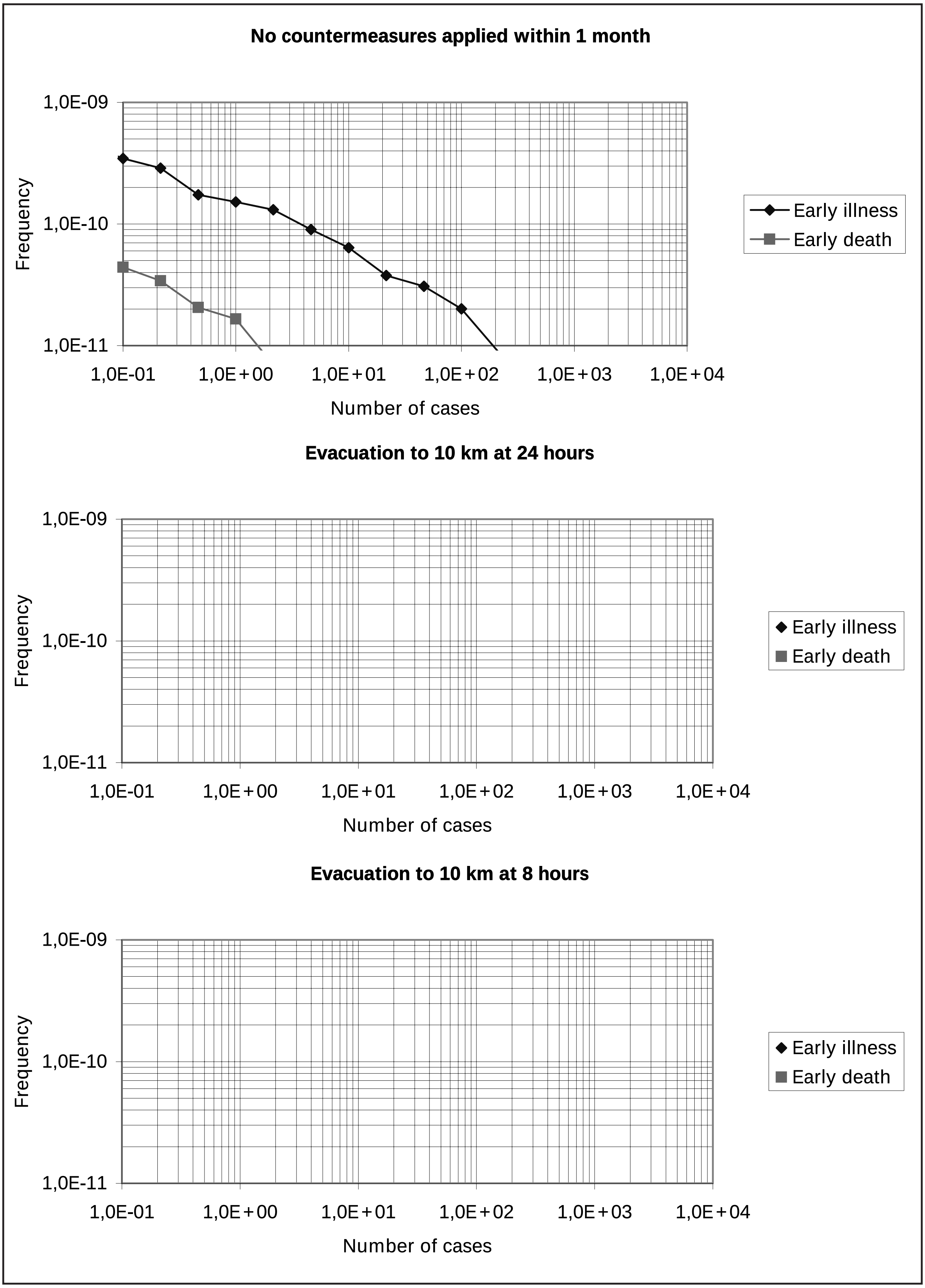


Fig. 11. *Early health effects from the Olkiluoto bin (VE_NCS-95 %) in three alternative countermeasure schemes. Frequency of this bin is 3.38E-9.*

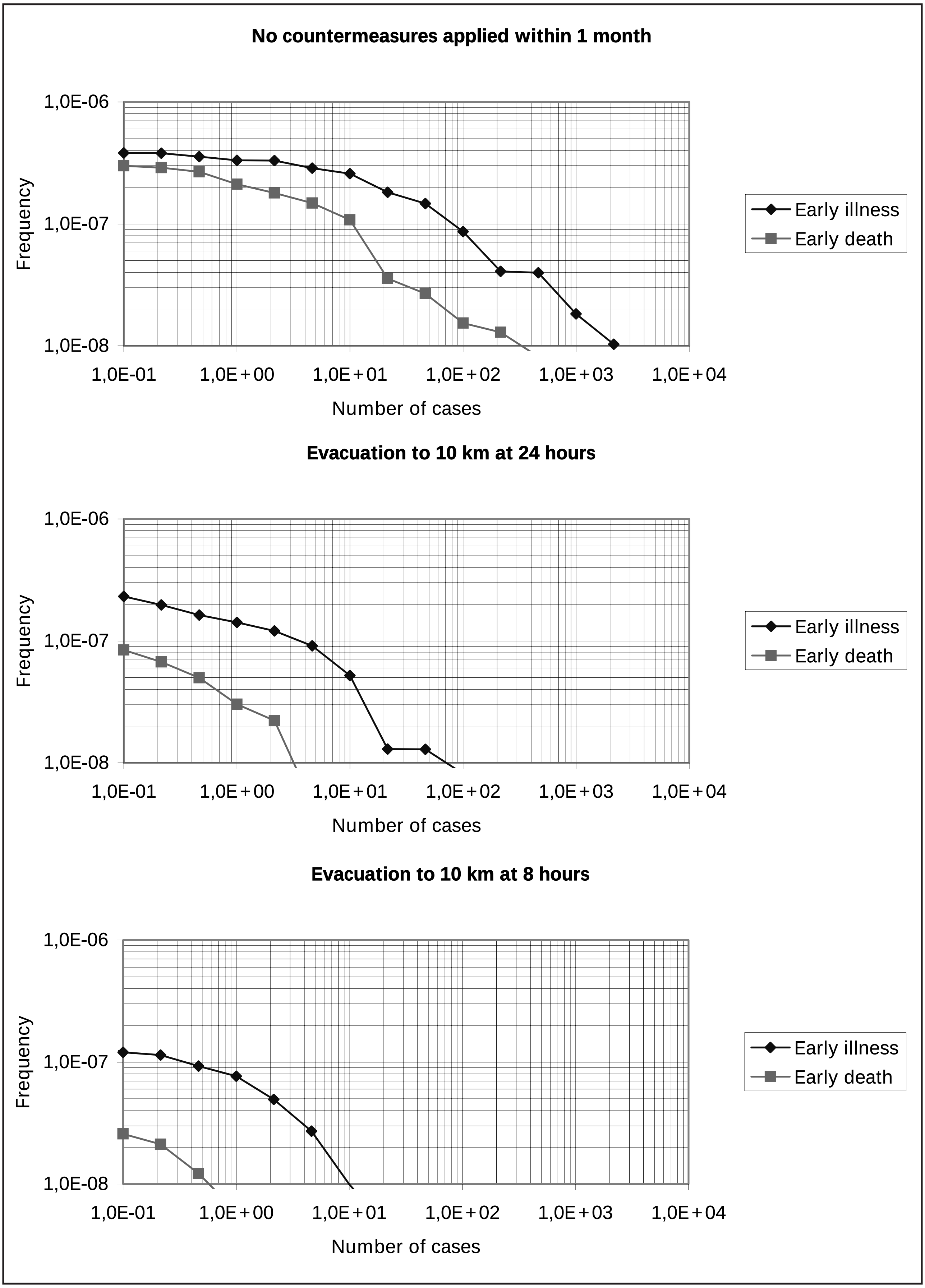


Fig. 12. *Early health effects from the Loviisa bin (BLTY, APC 6) in three alternative countermeasure schemes. Frequency of this bin is 4.82E-7.*

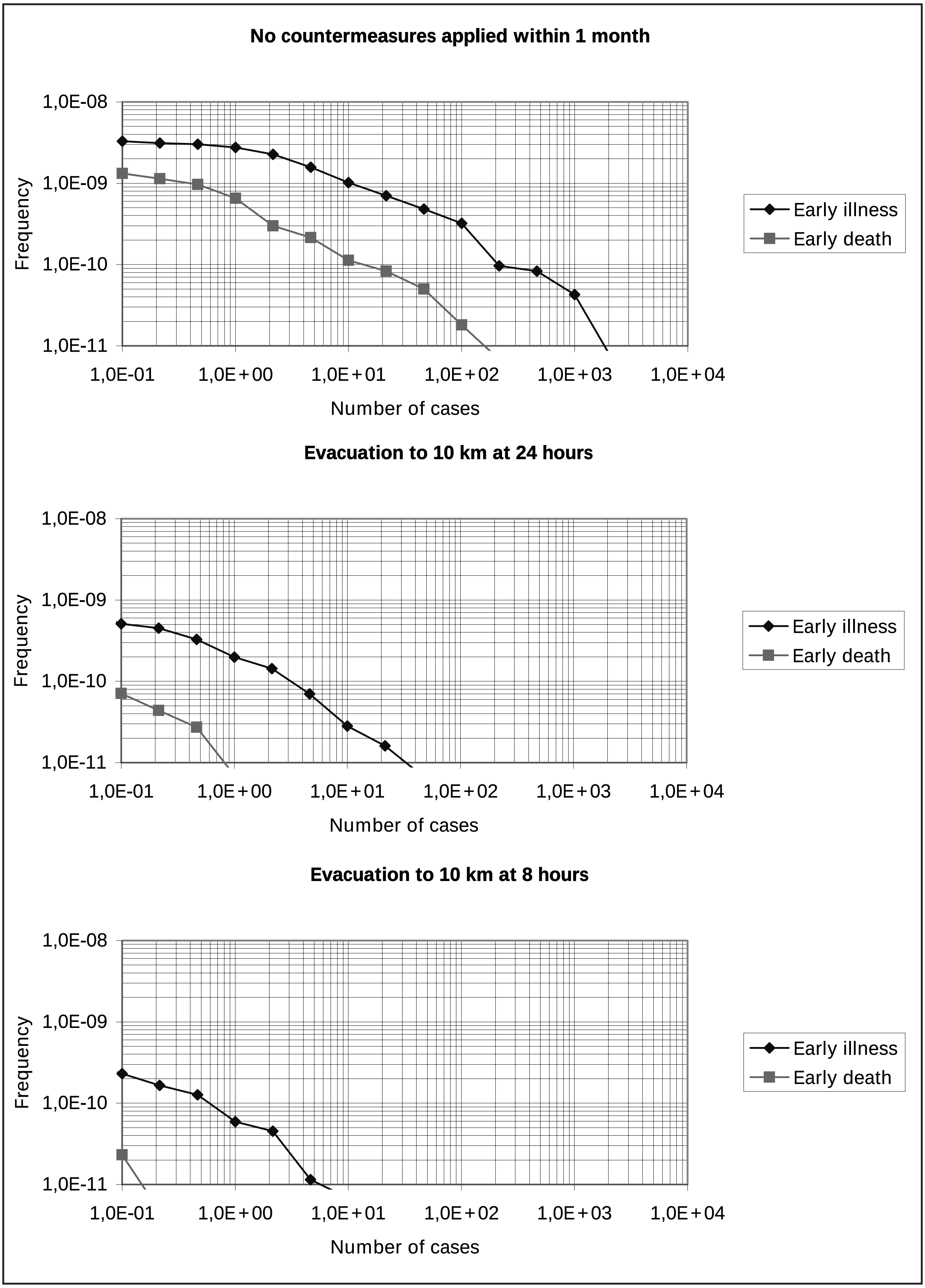


Fig. 13. *Early health effects from the Loviisa bin (NSIK, APC 22) in three alternative countermeasure schemes. Frequency of this bin is 5.90E-9.*

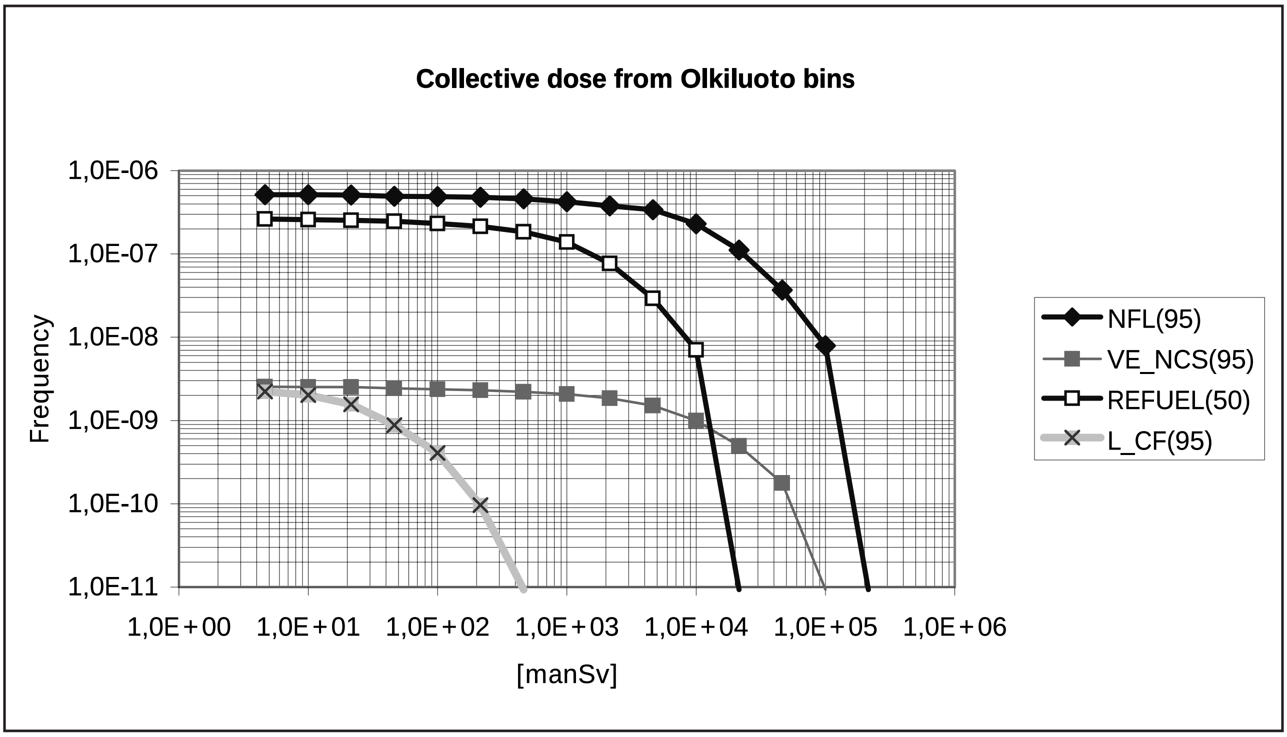


Fig. 14. *Collective doses from the Olkiluoto bins. The values 95 and 50 in the legend box correspond to the confidence level.*

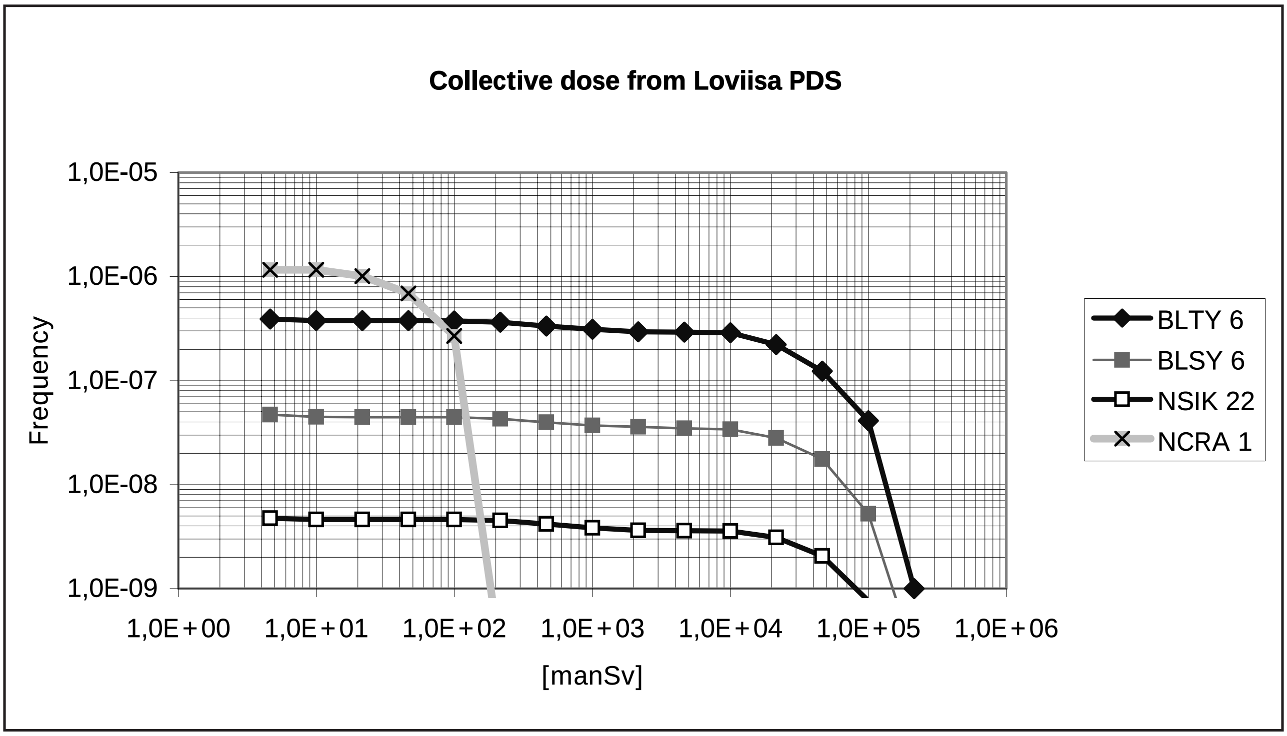
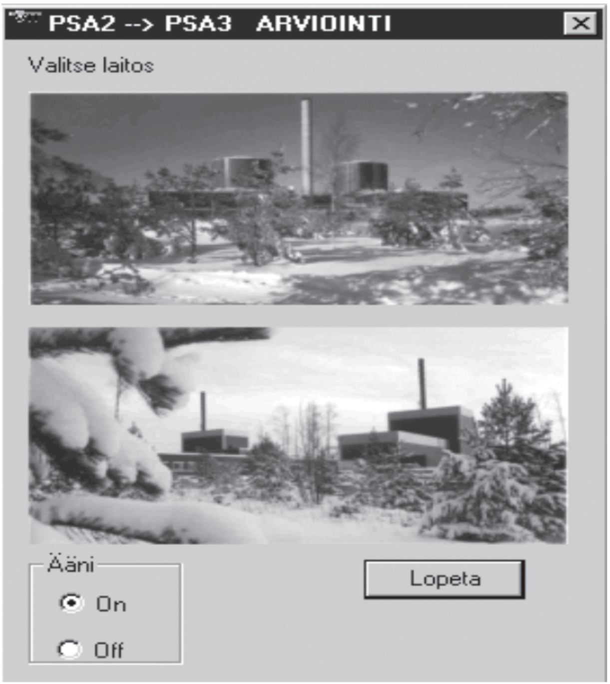
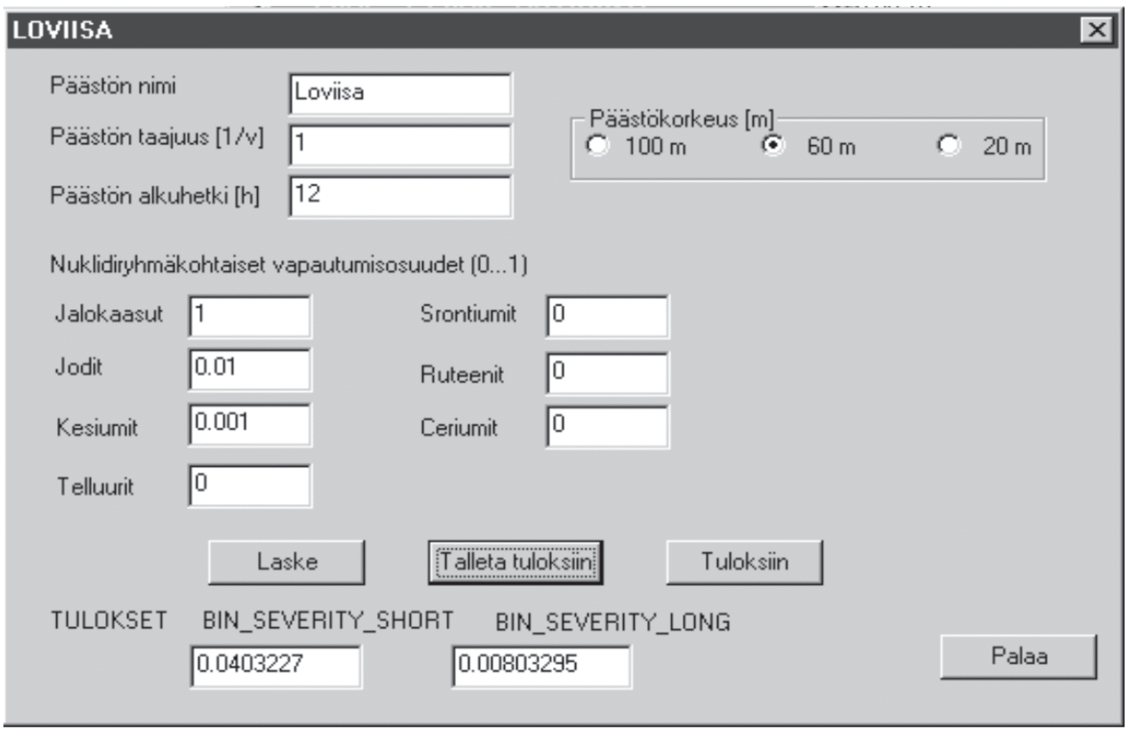


Fig. 15. *Collective doses from the Loviisa PDS. The values 6, 22 and 1 in the legend box correspond to accident progression category (APC).*

4 PROGRAM PSA23

To facilitate usage of the developed method a user interface including the classification procedure was prepared. This program, called PSA23, consists of three specific windows. First the power plant is to be selected. Then some key parameters can be inputted and the Bin_severities of short-term as well as long-term doses are calculated. User can save the results in the file and these results as well as the previous results can be surveyed in the third window. Scheme 1 illustrates the windows and structure of PSA23. For now PSA23 was tested in Windows NT, Windows 98 and Windows 95 environments. PSA23 could also be used in emergency exercises or drills to give first estimates of the accident severity, however recognising that plume dispersion occurs under certain prevailing conditions defined by measurements and forecasts but not by the mean weather conditions used in PSA23.

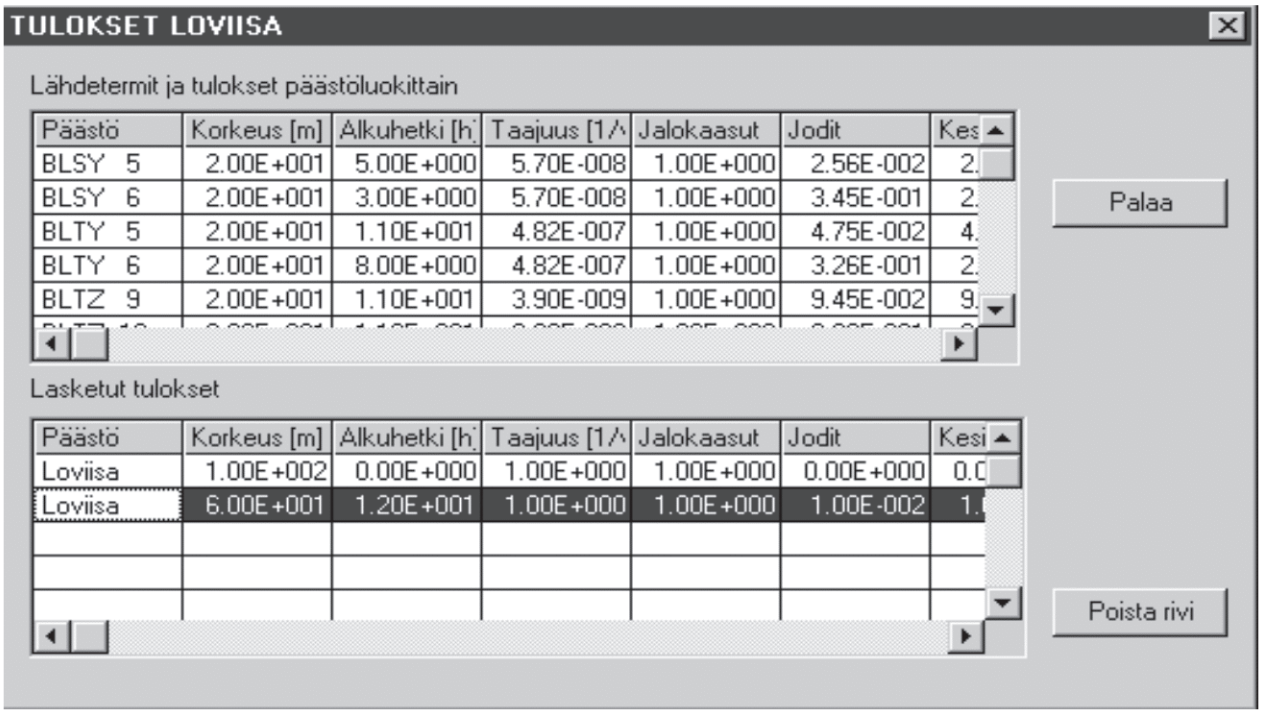




Scheme 1. *Flow chart of the Windows program for operational use.*

5 SUMMARY

A simplified procedure was developed to categorise any new result from the PSA level 2 for the level 3 based on environmental radiation dose estimates. In this method the significance factor of each nuclide group is first derived. Then these factors are multiplied with the release fraction of each nuclide group to obtain the final severity factor of the release. The method was programmed in the fast running computer code, in which both the Loviisa and Olkiluoto plants are presented. The existing precalculated results are supplied as a reference and a user can calculate and save new results with his own input values. In the future the procedure itself could be improved by taking into account more phenomena affecting dose calculations and the interactive user interface could be improved based on incoming user feedback.



Scheme 1. *(continued)*

REFERENCES

1 Savolainen I., Vuori S., Assessment of risks of accidents and normal operation at nuclear power plants. Espoo 1977. Technical Research Centre of Finland, Electrical and Nuclear Technology, Publication 21. 23 p. + app. 15 p.

2 Kattainen M., Lundström P., Pärssinen M., Routamo T., Result report. IVO Power Engineering Oy, LO1-K850-15, 21.3.1997. App. 9.1, 9.2, 10 and 11.

3 PSA, Rev 2, 31.12.1997, Chapters 2 and 9.8. Teollisuuden Voima Oy.

Nuclide inventory of the Olkiluoto BWR

APPENDIX 1

Nuclide inventory [Bq] of the Olkiluoto BWR reactor used in the calculations. Net electric power 840 MW. Parameters used in the ORIGEN2 calculations: element power $2.43 \cdot 10^{1}$ MW, burnup $4.0 \cdot 10^{4}$ MWD, flux $2.41 \cdot 10^{14}$ $N/cm^{2}s$. Nuclide specific activities are based on the reactor inventory at the end of five refuelling periods: 247, 614, 1070, 1482 and 1688 days. Assuming that the reactor has been operated for a long time there is always fuel in five age classes. Thus the average inventory can be obtained by weighting each of the five activity inventory value from ORIGEN by a factor of 0.2.

1	KR85	.000E+00	29	MI135	.410E+19	57	KR83M	.000E+00
2	KR85M	.565E+18	30	XE133	.437E+19	58	KR89	.186E+19
3	KR87	.108E+19	31	XE135	.141E+19	59	AG110M	.000E+00
4	KR88	.153E+19	32	CS134	.422E+18	60	SB124	.000E+00
5	SR89	.205E+19	33	CS136	.000E+00	61	XE131M	.000E+00
6	SR90	.202E+18	34	CS137	.284E+18	62	XE133M	.000E+00
7	SR91	.257E+19	35	BA140	.378E+19	63	XE135M	.861E+18
8	Y90	.209E+18	36	LA140	.390E+19	64	XE137	.383E+19
9	Y91	.263E+19	37	CE141	.359E+19	65	XE138	.361E+19
10	ZR95	.359E+19	38	CE143	.332E+19	66	RB86	.000E+00
11	ZR97	.360E+19	39	CE144	.270E+19	67	TE127	.000E+00
12	NB95	.359E+19	40	PR143	.327E+19	68	TE127M	.000E+00
13	MO99	.403E+19	41	ND147	.143E+19	69	SB127	.000E+00
14	TC99M	.353E+19	42	PU238	.786E+16	70	SB129	.691E+18
15	RU103	.330E+19	43	PU239	.916E+15	71	NP239	.447E+20
16	RU105	.226E+19	44	PU240	.128E+16	72	AM241	.409E+15
17	RU106	.121E+19	45	PU241	.333E+18	73	CM242	.111E+18
18	RH105	.213E+19	46	H3	.000E+00	74	CM244	.982E+16
19	TE129	.680E+18	47	C14	.000E+00	75	RB88	.155E+19
20	TE129M	.101E+18	48	N13	.000E+00	76	RB89	.199E+19
21	TE131M	.000E+00	49	AR39	.000E+00	77	Y91M	.149E+19
22	TE132	.305E+19	50	AR41	.000E+00	78	NB97	.363E+19
23	I131	.215E+19	51	CR51	.000E+00	79	RH103M	.298E+19
24	MI131	.000E+00	52	MN54	.000E+00	80	TE131	.191E+19
25	I132	.310E+19	53	FE59	.000E+00	81	BA137M	.269E+18
26	I133	.438E+19	54	CO58	.000E+00	82	CS138	.401E+19
27	I134	.481E+19	55	CO60	.000E+00	83	PR144	.271E+19
28	I135	.410E+19	56	ZN65	.000E+00	84	I129	.000E+00

APPENDIX 2

Nuclide inventory of the Loviisa PWR

Nuclide inventory [Bq] of the Loviisa PWR reactor used in the calculations. Net electric power 488 MW. Parameters used in the ORIGEN2 calculations: element power $3.68 \cdot 10^1$ MW, burnup $3.6 \cdot 10^4$ MWD, flux $3.41 \cdot 10^{14}$ N/cm²s. Nuclide specific activities are based on the reactor inventory at the end of three refuelling periods: 326, 672 and 1018 days. Assuming that the reactor has been operated for a long time there is always fuel in three age classes. Thus the average inventory can be obtained by weighting each of the three activity inventory value from ORIGEN by a factor of 0.33.

1	KR85	.101E+17	29	MI135	.260E+19	57	KR83M	.177E+18
2	KR85M	.379E+18	30	XE133	.279E+19	58	KR89	.127E+19
3	KR87	.732E+18	31	XE135	.763E+18	59	AG110M	.323E+16
4	KR88	.103E+19	32	CS134	.141E+18	60	SB124	.131E+16
5	SR89	.141E+19	33	CS136	.571E+17	61	XE131M	.151E+17
6	SR90	.785E+17	34	CS137	.105E+18	62	XE133M	.865E+17
7	SR91	.173E+19	35	BA140	.242E+19	63	XE135M	.539E+18
8	Y90	.818E+17	36	LA140	.247E+19	64	XE137	.243E+19
9	Y91	.180E+19	37	CE141	.232E+19	65	XE138	.232E+19
10	ZR95	.235E+19	38	CE143	.214E+19	66	RB86	.203E+16
11	ZR97	.231E+19	39	CE144	.150E+19	67	TE127	.139E+18
12	NB95	.234E+19	40	PR143	.212E+19	68	TE127M	.176E+17
13	MO99	.254E+19	41	ND147	.908E+18	69	SB127	.142E+18
14	TC99M	.222E+19	42	PU238	.207E+16	70	SB129	.428E+18
15	RU103	.201E+19	43	PU239	.441E+15	71	NP239	.272E+20
16	RU105	.132E+19	44	PU240	.472E+15	72	AM241	.111E+15
17	RU106	.532E+18	45	PU241	.133E+18	73	CM242	.278E+17
18	RH105	.122E+19	46	H3	.548E+15	74	CM244	.153E+16
19	TE129	.421E+18	47	C14	.315E+12	75	RB88	.105E+19
20	TE129M	.628E+17	48	N13	.000E+00	76	RB89	.135E+19
21	TE131M	.194E+18	49	AR39	.000E+00	77	Y91M	.100E+19
22	TE132	.193E+19	50	AR41	.000E+00	78	NB97	.233E+19
23	I131	.135E+19	51	CR51	.711E+14	79	RH103M	.181E+19
24	MI131	.000E+00	52	MN54	.622E+13	80	TE131	.120E+19
25	I132	.196E+19	53	FE59	.300E+13	81	BA137M	.100E+18
26	I133	.279E+19	54	CO58	.334E+14	82	CS138	.257E+19
27	I134	.306E+19	55	CO60	.768E+14	83	PR144	.151E+19
28	I135	.260E+19	56	ZN65	.170E+14	84	I129	.000E+00

Naming of the Loviisa source terms

APPENDIX 3

Naming of the Loviisa source terms for calculations. The complete specification is found in [2].

No	Release	APC	No	Release	APC
1	BLSY	5	44	NMIA	19
2	BLSY	6	45	NMID	6
3	BLTY	5	46	NMIE	8
4	BLTY	6	47	NMIF	10
5	BLTZ	9	48	NMIH	14
6	BLTZ	10	49	NMII	16
7	BMIY	6	50	NMIJ	21
8	BMIZ	10	51	NMIL	23
9	BMLY	6	52	NSEA	1
10	BMLZ	10	53	NSIA	1
11	BSAY	6	54	NSIA	18
12	BSAZ	10	55	NSIA	19
13	BSUY	6	56	NSID	6
14	BVAY	6	57	NSIE	8
15	BVAY	8	58	NSIF	10
16	BVAZ	10	59	NSIG	12
17	BVAZ	12	60	NSIG	20
18	BVBY	6	61	NSIH	14
19	BVBY	8	62	NSII	16
20	BVCY	6	63	NSII	20
21	BVCY	8	64	NSIJ	21
22	BVCZ	10	65	NSIK	22
23	BVCZ	12	66	NSIM	24
24	BVDY	6	67	NXLA	1
25	BVDY	8	68	NXLA	18
26	NCRA	1	69	NXLA	19
27	NCRA	18	70	NXLD	6
28	NCRA	19	71	NXLE	8
29	NCRD	6	72	NXLE	9
30	NCRH	14	73	NXLE	20
31	NCRJ	21	74	NXLG	12
32	NCRM	24	75	NXLH	14
33	NLEA	1	76	NXLI	16
34	NLIA	1	77	NXLI	17
35	NLIA	19	78	NXLJ	21
36	NLID	6	79	NXLK	22
37	NLIE	8	80	NXLM	24
38	NLIF	10	81	NXSA	1
39	NLIJ	21	82	NXSA	19
40	NLIL	23	83	NXSG	12
41	NMEA	1	84	NXSG	13
42	NMIA	1	85	NXSI	16
43	NMIA	18	86	NXSK	22

APPENDIX 4 NAMING OF THE OLKILUOTO SOURCE TERMS

Naming of the Olkiluoto source terms for calculations. The complete specification is found in [3].

No	Release	Bin
1	REFUEL	Mean
2		5 %
3		50 %
4		95 %
5	NFL	Mean
6		5 %
7		50 %
8		95 %
9	VE_CS	Mean
10		5 %
11		50 %
12		95 %
13	NVB	Mean
14		5 %
15		50 %
16		95 %
17	INTACT	Mean
18		5 %
19		50 %
20		95 %
21	E_CF	Mean
22		5 %
23		50 %
24		95 %
25	L_CF	Mean
26		5 %
27		50 %
28		95 %
29	D0ME	Mean
30		5 %
31		50 %
32		95 %
33	VENT	Mean
34		5 %
35		50 %
36		95 %
37	VE_NCS	Mean
38		5 %
39		50 %
40		95 %
41	VL_CF	Mean
42		5 %
43		50 %
44		95 %
45	N0_CM	Mean
46		5 %
47		50 %
48		95 %
49	FCF_LE	Mean
50		5 %
51		50 %
52		95 %