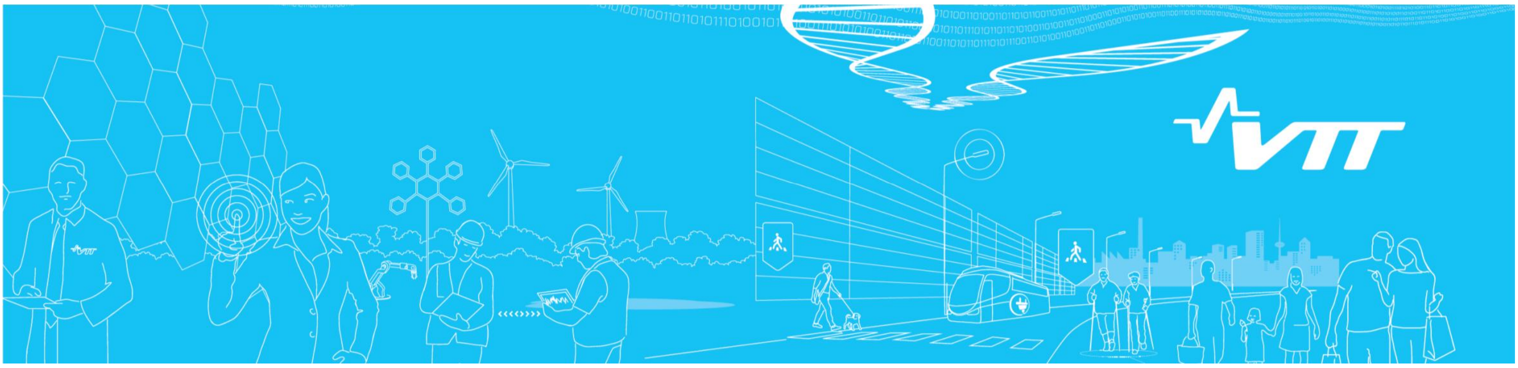

RESEARCH REPORT

VTT-R-05661-14

Applying IDPSA in PSA level 3 – a pilot study

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Confidentiality: Public

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Summary

This report is a pilot study of applying deterministic and probabilistic methods in level 3 probabilistic safety analysis (PSA). On the deterministic side, VTT's consequence analysis code ARANO is used in calculating the atmospheric dispersion of a release of radioactive substances, and in estimating the total dose of ionizing radiation. On the probabilistic side, VTT's level 2 PSA code SPSA is used to assess the probabilities of different consequences. The main model is an event tree, where each branch concerns either the value of a weather variable (wind direction, wind speed, precipitation) or a countermeasure variable (evacuation success, sheltering success).

The case considered is an alternative take on the Fukushima Daiichi nuclear power plant accident. The setup is as follows: the population of the major cities close to the site are in place (and not killed by or evacuated after the earthquake and tsunami), and the impact of weather is analysed on the basis of what it statistically is in March in that part of Japan. What radiological consequences (in terms of population dose and cancer deaths) would the radioactive release from the site have had under these presuppositions?

The population doses are analysed in the event tree, and uncertainty analyses are conducted on the weather variables, evacuation and sheltering success probabilities, and the effectiveness of sheltering. We find that, even under rather conservative assumptions, the radiological consequences are small. However, the results should be seen as only indicative due to simplifications made in modelling.

The pilot study demonstrates that the approach used is a viable way of conducting level 3 analyses.

Confidentiality	Public

Espoo 24.4.2015

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Preface

This report is a result of the PRADA project, which in turn is a part of the SAFIR 2014 research programme. On the other hand, the report is a part of Nordic cooperation in the “Addressing off-site consequence criteria using Level 3 PSA” project which has received funding from NKS and NPSAG.

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Authors

Contents

1. Introduction

Integrated deterministic and probabilistic safety analysis (IDPSA) means the coupling of deterministic and probabilistic methods of safety analysis to address the mutual interactions of stochastic disturbances (e.g. equipment failure) and the deterministic response (transients) (Adolfsson et al. 2012). It has so far been used mainly in level 2 probabilistic safety analysis (PSA) of nuclear power plants.

Level 3 PSA concerns the consequences of a radioactive release from a nuclear power plant, or more precisely, the offsite dispersion and transport of radionuclides released to the environment and the health effects and other consequences of the postulated accidents (Lee and McCormick 2011).

From the beginning, both deterministic and probabilistic considerations have been a part of level 3 PSA (Bayer et al., 1981). However, the probabilistic side has usually been handled by adding random variables, with estimated or postulated probability distributions, to the deterministic variables describing e.g. atmospheric dispersion or dose of ionizing radiation to a group of people, and the analysis has normally been limited to Monte Carlo simulations and sensitivity analyses. Hence, the question arises whether more systematic and sophisticated probabilistic models might bring added value to level 3 analyses. This report describes an experiment in the application of event trees, throught IDPSA, to level 3 consequence analysis of health effects.

2. Goal

This report presents a pilot study in level 3 PSA.

The main goal of the pilot is to study how to apply the IDPSA methodology on level 3 PSA. There are also other goals:

- To illustrate how to apply a particular risk measure on level 3, namely the number of cancers resulting from a radioactive release.
- To enable comparison to the Swedish method of conducting level 3 PSA.
- Facilitate level 3 PSA software development. It is hoped that the construction of the pilot reveals targets of development in the SPSA software, and provide experience of level 3 analyses needed in level 3 software development.

3. Description of the pilot case

In this report, we do an exercise in alternative history: what would the consequences of the Fukushima Daiichi nuclear accident have been if a similar accident, with the source term of the actual accident of March 2011, had happened so that the population had not been decimated by the tsunami and evacuated after that, but instead had been in their places, and evacuated only after the nuclear accident.

The motivation for the case study comes from the fact that the Fukushima Daiichi accident had very small radiological consequences: it has been estimated that the radioactive release will produce no extra deaths in the general public (UNSCEAR 2013), and probably none even in plant and rescue workers. On the other hand, in the first few days of the release, wind blew dominantly to the Pacific Ocean, thus saving the population from exposure. Therefore it is of interest to find out whether the near nonexistence of radiological consequences was due to good luck and the deflation of the nearby areas from population after the tsunami, or was it to be expected given the weather conditions in Japan and the efficiency of the evacuation within the evacuation zone.

We assume that the release would have been much more abrupt than it was (in reality there were multiple releases over several months). We assume that the whole release would have happened in three hours. As the source term, we use the actual source term of Fukushima. Assuming such a short release time span is conservative, but can be justified on the basis that much of the release at Chernobyl happened in a few hours, and the source term there was an order of magnitude bigger than that in Fukushima Daiichi.

Table 1. The source term of the Fukushima Daiichi nuclear power plant accident (UNSCEAR 2013).

Radionuclide	Total release (PBq) to the atmosphere
Te-132	29
I-131	120
I-132	29
I-133	9.6
Xe-133	7 300
Cs-134	9.0

Cs-136	1.8
Cs-137	8.8

For weather, we do not assume the weather of March 2011, but weather conditions in that part of Japan in March generally.

The evacuation proceeded in Fukushima as follows:

Table 2. Evacuation-related events in the Fukushima prefecture, March 2011 (UNSCEAR 2013).

Event	Date	Time
earthquake	11.3.2011	14:46
tsunami	11.3.2011	15:35
evacuation within 2 km ordered	11.3.2011	20:50
evacuation within 10 km ordered	12.3.2011	5:44
evacuation within 20 km ordered	12.3.2011	18:25
sheltering within 30 km, evacuation within 20 km completed	15.3.2011	11:00

We consider population doses (and from that, the theoretical number of cancers as 0.05 x population dose) in five cities closest to the Fukushima Daiichi NPP site. The cities are given in Table 3 (population data are from Wikipedia).

Table 3. Cities considered in health consequence calculations.

Name	Point of compass from Fukushima Daiichi	Distance from Fukushima Daiichi, kilometers	Population
Minamisoma	north	27	71 000
Kakuda	north	58	31 000
Fukushima	northwest	64	294 000
Koriyama	west	56	338 000
Iwaki	south southwest	48	345 000

4. Limitations

This study is a demonstration of how the integrated deterministic and probabilistic safety analysis (IDPSA) framework may be applied to level 3 PSA studies. The case chosen – what the radiation doses to the population could have been if the Fukushima Daiichi nuclear accident would have taken place in the weather circumstances generally prevailing in the Fukushima province in March (and not the particular weather of March 2011), assuming the evacuation of the surroundings would not have proceeded as it actually did, and with a release far more rapid than the actual – does not reflect what actually happened in Fukushima, March 2011. The results obtained should be seen as indicative and not as reliable estimates of release consequences even in this alternative scenario.

5. The model

The general architecture of the model is as follows. The deterministic part covers atmospheric dispersion and population dose calculation in given weather conditions, which was implemented in ARANO (Savolainen and Vuori 1977), VTT's consequence analysis code. The probabilistic part covers the assessment of the probabilities of various consequences, and incorporates the probabilities of different weather conditions, and evacuation and sheltering success probabilities. The probabilistic part is modelled by an event tree; the population dose resulting from each sequence in the event tree was calculated in ARANO. The probabilistic part was implemented in SPSA, VTT's code for level 2 PSA.

The number of cancer deaths caused by the ionizing radiation of the release was calculated from population dose as 0.05 times the population dose (manSv). This is the estimate used generally.

In the rest of the sections of this chapter, first the event tree model is described in section 5.1, then the weather model (which gives the weather-related probabilities to the event tree) is explained in section 5.2, the evacuation and shielding models (which give the success probabilities of evacuation and shielding to the event tree model) are presented in section 5.3, and uncertainty distributions used in uncertainty analysis are presented in section 5.4.

5.1 Event tree model

The event tree model is presented in Appendix A. The event tree model includes five sections:

- Wind speed: 16 m/s, 8 m/s or 0 m/s
- Wind direction: northwest, west, north, south southwest or other
- Precipitation: 5 mm/hour or 0 mm/hour
- Population sheltering: in time or not
- Evacuation: in time or not (for north direction, only Kakuda might be evacuated)

For each end point of the event tree without evacuation and sheltering, the population dose was calculated by ARANO software. For the end points with sheltering but without evacuation, the population doses obtained from ARANO were multiplied by a 'sheltering factor' (see section 5.3). For the end points with evacuation or wind direction 'other', the population dose was assumed to be 0. The population dose from the release was assumed to be 0, when the wind speed was under 4 m/s. The justification for this is that 1) a mild wind does not carry the radionuclides far from the site, and 2) there will be plenty of time for evacuation, and therefore the cities in the direction of the wind would be void of people when the radioactive plume would finally arrive.

5.2 Weather data

The weather data used has been collected from a variety of sources.

The wind speed statistics are from Onahama, which is in the Fukushima prefecture, some 60 kilometers to the south of the Fukushima Daiichi nuclear power plant site.
http://www.windfinder.com/windstatistics/onahama

The site contains wind direction distributions in the form of Rose diagrams for each month, and also on the yearly level. We used the distribution for March, for reasons stated in the description of the problem.

The wind direction statistics were obtained from the Rose diagram of directions on the web page, and are approximately as follows:

Table 4. Average wind direction distribution in Onahama, Fukushima prefecture, Japan in March. Only the directions that point to land from Fukushima Daiichi are shown.

Wind direction (from)	Wind direction (to)	Approximate proportion, %
North	South	7.6
North northeast	South southwest	9.7
Northeast	Southwest	5.9
East northeast	West southwest	2.7
East	West	2.7
East southeast	West northwest	2.7
Southeast	Northwest	3.8
South southeast	North northwest	6.5
South	North	11.4

A log-normal distribution was postulated for wind speed. From the Onahama statistics it was obtained that the average wind speed in March is 8 knots or 4.116 m/s. According to the site, the probability of wind speed exceeding 4 Beaufort in March is 19 %. 4 Beaufort is 20-28 km/h, and therefore this probability may be interpreted as the probability that wind speed exceeds 20 km/h = 5.556 m/s. For the log-normal distribution, the following two equations hold (Bury 1999):

$$\bar{x} = e^{\mu + \frac{\sigma^2}{2}} \tag{1}$$

$$F(x;\mu,\sigma) = \Phi\left(\frac{\ln(x) - \mu}{\sigma}\right) \tag{2}$$

Where $\Phi(x)$ is the standard cumulative normal distribution function, and μ and σ are the parameters of the log-normal distribution. These two nonlinear equations suffice to determine the parameters, noting that $\bar{x} = 4.116$ and $F(5.556;\mu,\sigma) = 1 - 0.19 = 0.81$. Through simple line search on equations on (1) and (2), it was found that the parameters of the log-normal distribution are approximately μ = 0.58144 and σ = 1.290995.

The wind speeds considered in the deterministic analyses were 0, 8 and 16 m/s. These wind speeds each represent a range of actual wind speeds in the model. It was decided that wind speed 0 m/s represents actual wind speeds of 0-4 m/s, wind speed 8 m/s represents actual wind speeds of 4-12 m/s, and 16 m/s presents any wind speed over 12 m/s. From the log-normal distribution with the parameters of the previous paragraph, the probabilities of the wind speeds are

Table 5. Probabilities of wind speed ranges in Onahama, Fukushima prefecture, Japan, from the postulated log-normal model.

Wind speed used in deterministic calculations (m/s)	Wind speed range the wind speed used represents (m/s)	Probability of the wind speed range from the postulated log-normal distribution
0	0-4	0.733501384
8	4-12	0.196314116
16	12-	0.070185

Precipitation statistics for Onahama were obtained from http://www.yr.no/place/Japan/Fukushima/Onahama/statistics.html. The average number of days with precipitation for March is 8, and therefore the probability of rain at the time of the release was set to 8/31≈0.258. It was assumed that the amount of rainfall (if it rains) concentrates on the value used, namely 5 mm/hour. It is evident that a more sophisticated analysis would take into account the probability distribution of rainfall, and even its dynamic nature.

5.3 Evacuation and shielding models

We define evacuation success to mean that evacuation has been completed before the release plume arrives.

If the release plume arrives before the population has been evacuated or sheltered, the population is assumed to be outdoors 10% of the time and indoors 90% of the time.

Evacuation success probability is calculated as follows. With a given wind speed v and given distance x from the site, it takes t1=x/v seconds for the plume to reach the city. This time is compared to the time it took to empty the evacuation zone in the Fukushima prefecture from people in March 2011. The time it takes for the plume to arrive from the site to the city is divided by the time it takes to evacuate the city, and this ratio is taken as the evacuation success probability (if it takes more time for the plume to reach the city than the evacuation in Fukushima in 2011, the evacuation is considered a success with probability 1).

If such an acute and large release as postulated in this report would have actually happened, it is natural to assume that evacuation would have been ordered at the latest when the release started. As seen in Table 2, the evacuation of the 20 kilometer zone in Fukushima was ordered on 12.3.2011 at 18:25, and was completed on 15.3.2011 at 11:00. Thus it took 2 days, 16 hours and 35 minutes, or 232 500 seconds. In the calculations, this reference evacuation time is rounded to 3 days.

In the calculations, it is assumed that the population is 10% of the time outdoors. Considering this sheltering does not decrease the population dose much. It is assumed that with sheltering the population dose is 70% of the population dose without sheltering. The probability of sheltering is set to 0.8 by expert's judgement.

5.4 Uncertainty distributions

To perform uncertainty analysis, uncertainty distributions are assigned to wind speed probabilities, wind direction probabilities, the probability of rain, population sheltering probability and the portion of the dose population is exposed when sheltered. With very little knowledge of the uncertainties, the uniform distributions presented in Table 6 are used.

Table 6. The limits of the uniform uncertainty distributions of the parameters.

Parameter	**Minimum**	**Maximum**
Probability of wind 16 m/s	0.0502	0.0902
Probability of wind 8 m/s	0.176	0.216
Probability of wind to Northwest	0.018	0.058
Probability of wind to West	0.007	0.047
Probability of wind to North	0.094	0.134
Probability of wind to South southwest	0.077	0.117
Probability of rain	0.158	0.358
Probability of sheltering	0.6	1.0
Portion of the dose population is exposed when sheltered	0.5	0.9

6. Results

The expected number of cancer deaths was 16. Table 7 presents the results for different wind directions and other conditions. Figure 1 presents Farmer's curve representing the probability for having at least considered number of cancer deaths. With probability 0.927 there are no cancer deaths at all.

Table 7. Results of the event tree calculations.

Conditions	Northwest	West	North	South southwest
Wind 8 m/s, no rain, no sheltering	Prob = 1.1E-3 Cancers = 220	Prob = 7.7E-4 Cancers = 320	Prob = 3.3E-3 Cancers = 210	Prob = 2.8E-3 Cancers = 410
Wind 8 m/s, no rain, sheltering	Prob = 4.3E-3 Cancers = 150	Prob = 3.1E-3 Cancers = 220	Prob = 1.3E-2 Cancers = 150	Prob = 1.1E-2 Cancers = 290
Wind 8 m/s, rain, no sheltering	Prob = 3.7E-4 Cancers = 180	Prob = 2.7E-4 Cancers = 270	Prob = 1.1E-3 Cancers = 190	Prob = 9.6E-4 Cancers = 350
Wind 8 m/s, rain, sheltering	Prob = 1.5E-3 Cancers = 120	Prob = 1.1E-3 Cancers = 190	Prob = 4.6E-3 Cancers = 140	Prob = 3.8E-3 Cancers = 240
Wind 16 m/s, no rain, no	Prob = 3.9E-4	Prob = 2.8E-4	Prob = 1.2E-3	Prob = 1.0E-3

sheltering	Cancers = 220	Cancers = 320	Cancers = 210	Cancers = 410
Wind 16 m/s, no rain, sheltering	Prob = 1.6E-3 Cancers = 150	Prob = 1.1E-3 Cancers = 220	Prob = 4.7E-3 Cancers = 150	Prob = 4.0E-3 Cancers = 290
Wind 16 m/s, rain, no sheltering	Prob = 1.4E-4 Cancers = 180	Prob = 9.6E-5 Cancers = 270	Prob = 4.1E-4 Cancers = 190	Prob = 3.5E-4 Cancers = 350
Wind 16 m/s, rain, sheltering	Prob = 5.4E-4 Cancers = 120	Prob = 3.9E-4 Cancers = 190	Prob = 1.6E-3 Cancers = 140	Prob = 1.4E-3 Cancers = 240
Total	Prob = 1.0E-2 Cancers = 150	Prob = 7.2E-3 Cancers = 230	Prob = 3.0E-2 Cancers = 160	Prob = 2.6E-2 Cancers = 300
Expected cancers	1.5	1.7	4.8	7.8

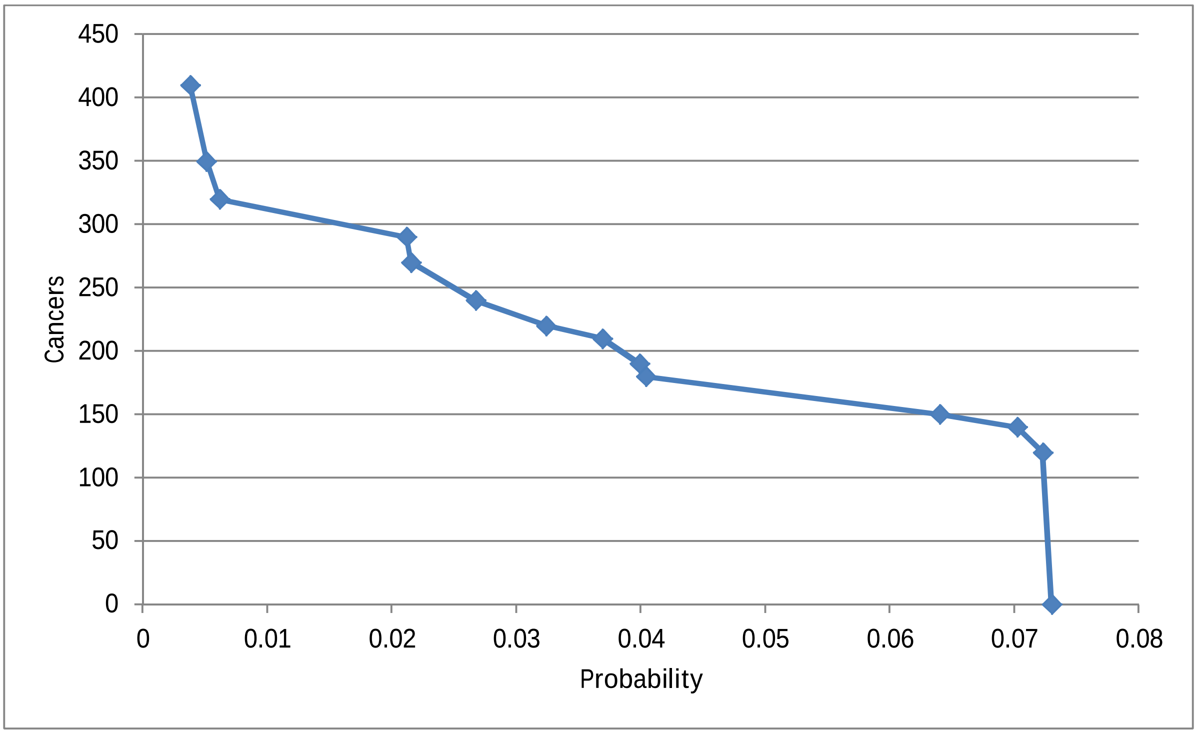

Figure 1: Farmer's curve.

The sensitivity of the expected number of cancer deaths to the evacuation probabilities was also studied. The chosen evacuation probabilities in this study were so small (< 0.05) that the results were almost same as when assuming evacuations impossible. However, choosing larger evacuation probabilities reduced the expected number of cancers. When evacuation probabilities were multiplied by 10, the expected number of cancers was 13. When evacuation probabilities were multiplied by 20, the expected number of cancers was 9.8. When evacuation probabilities were multiplied by 30, the expected number of cancers was 6.8. When evacuation probabilities were set close to 1, the expected number of cancers was close to 0.

Uncertainty analysis with 10000 simulations based on uncertainties presented in Section 5.4 resulted with the cumulative distributions of cancer deaths and probability presented in Figures 4 and 5. The results indicate that the expected number of cancers is between 10 and 20 with a probability of 0.95 approximately. The probability of anyone getting a cancer is 0.1 at maximum.

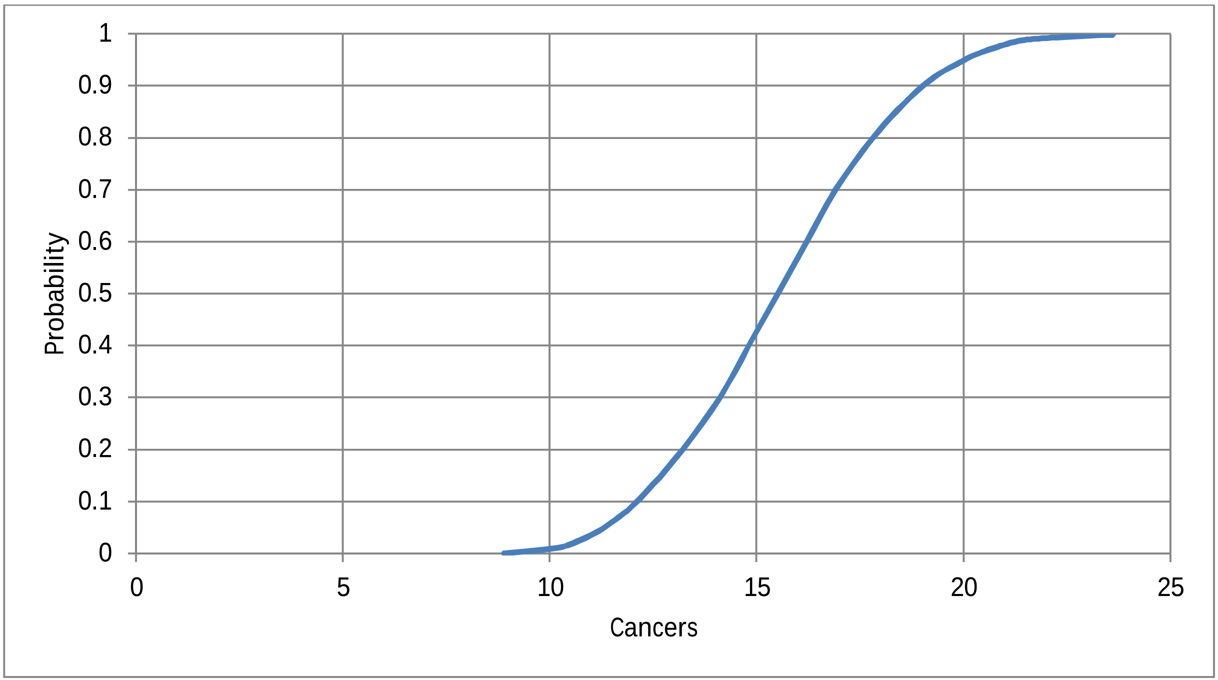

Figure 2: The cumulative uncertainty distribution of the number of cancers.

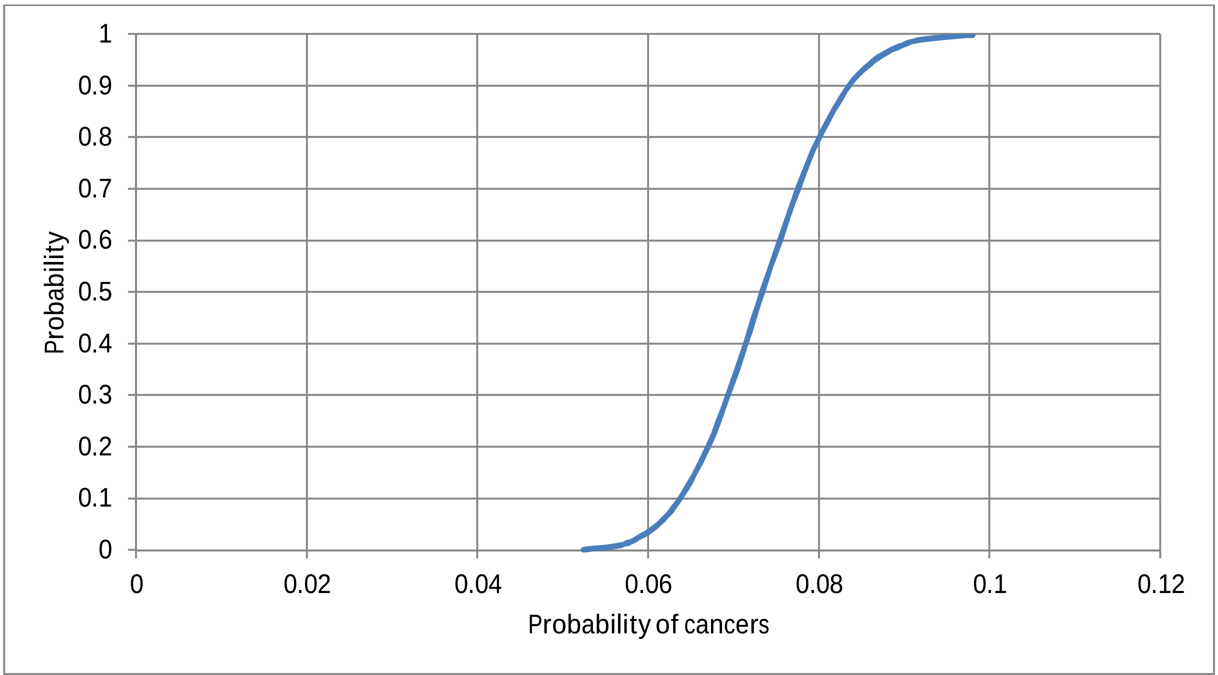

Figure 3: The cumulative uncertainty distribution of the probability of cancers.

7. Conclusions

We have modelled and analyzed a case of alternative history – what would have happened if the source term of the Fukushima Daiichi NPP accident would have been released rapidly and the population of the big towns near the NPP site would have been in place (instead of evacuated or killed by the tsunami), under weather conditions in that part of Japan in March – in order to assess what the radiological consequences would have been in terms of cancer deaths.

The overall number of cancer deaths resulting from the release is very low considering the number of people in the area. There were approximately 1 079 000 inhabitants in the cities considered in March 2011 prior to the earthquake and the tsunami. The expected number, given by our model, of cancer deaths resulting from the release is 16, with very high probability (0.927) there will be no cancer deaths, and the maximum expected number of cancer deaths under the most adverse conditions is 410. Even the largest number of cancer deaths due to the release is well below what can be detected as an increase in a population of that size when random fluctuations in cancer deaths is taken into account. Approximately 1/5 of the population will die of cancer due to reasons not related to the radioactive release; in the case of the towns considered, this amount to 216 000 cancer deaths.

The chosen methodology – using an event tree model for probabilistic considerations, and calculating atmospheric dispersion and population dose deterministically – seems to be fit for the purpose of level 3 PSA analyses. It makes the heavy computational load of atmospheric dispersion calculations manageable, while at the same time it provides the benefits of probabilistic analysis in terms of uncertainty handling (probability distributions). The size of the event tree will remain moderate even if a more detailed model is constructed, and the parameters needed in the model can either be calculated from weather data, or – in the case of countermeasure (evacuation, sheltering) success probabilities – be estimated from evacuation models or be assessed by expert judgment.

The model developed is rather coarse and can be considered to give indicative results at best. There are several ways in which to improve the model's accuracy. Concerning the modeling of weather, wind direction cannot be changed in ARANO (wind direction remains the same during the release and atmospheric dispersion); however, some codes, such as CALPUFF, are freely available that can handle dynamic weather conditions during the atmospheric dispersion. In these codes, also precipitation can be modelled in a more accurate way.

The actual release of Fukushima might be modelled more accurately in other ways, too. The release took place over an extended period of time (several months, with small releases even after that), and varied in both intensity and isotope content. This could be modelled by several releases that could follow a stochastic process in the model.

Evacuation has been taken into account in our model in a rudimentary manner that does not take into account the size of the population to be evacuated, the existence (or not) of evacuation plans, the quality of official actions in conducting the evacuation, possibly adverse weather and other conditions, the risks involved in evacuation etc. More refined evacuation models might shed light on the effects of these factors.

Due to practical reasons, a comprehensive sensitivity and uncertainty analysis, covering both the deterministic and probabilistic parts of the model, was not possible. It is evident that a comprehensive uncertainty analysis would yield valuable information about uncertainties.

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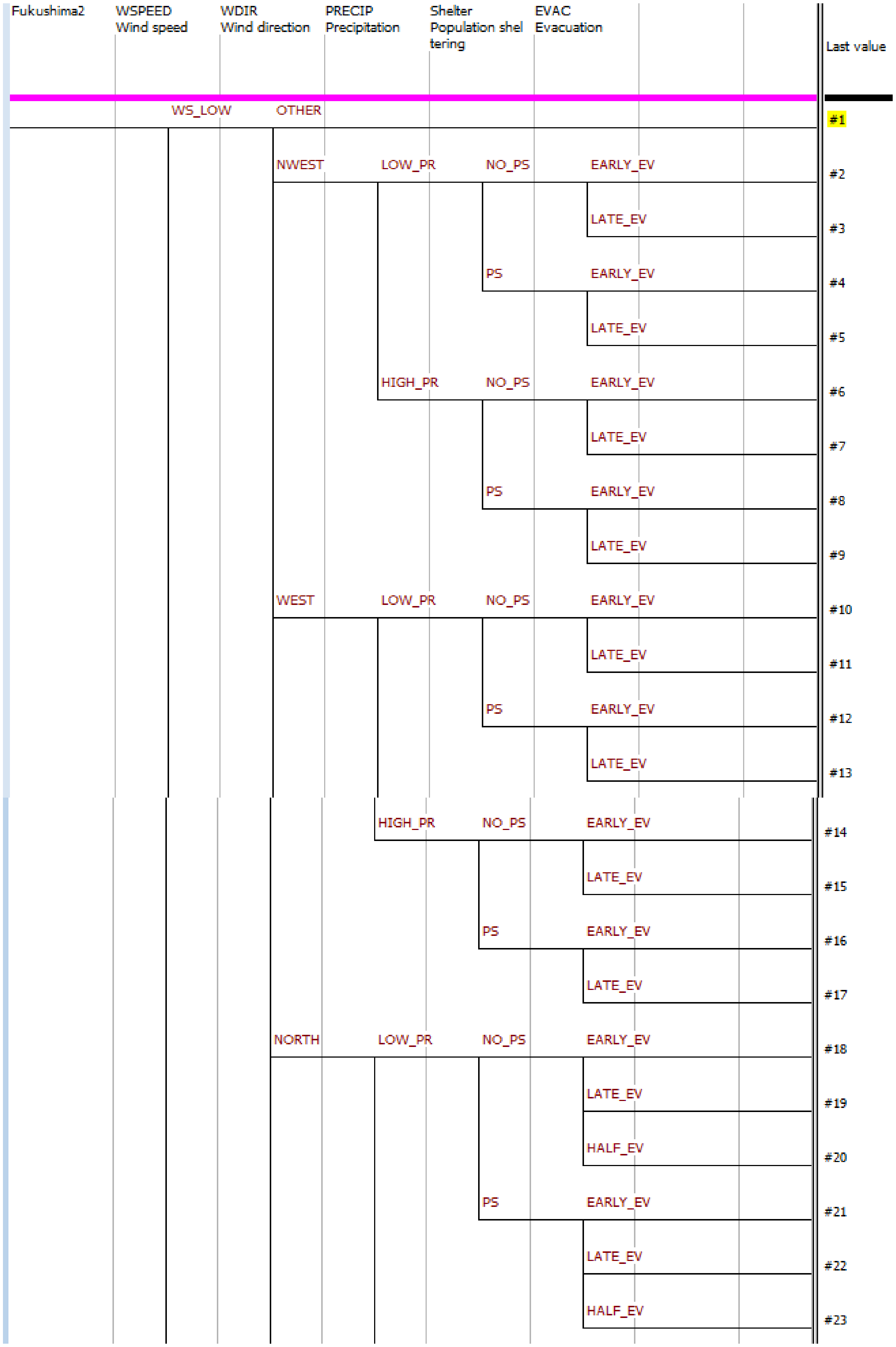
Appendix A

The event tree model is presented in the following. Some function names are explained in Table 8.

Table 8. Descriptions of functions in the event tree model.

Function	Desciption
WS_LOW	Wind speed 8 m/s
WS_HIGH	Wind speed 16 m/s
LOW_PR	No rain
HIGH_PR	Precipitation 5 mm/hour
NO_PS	No population sheltering
PS	Successful population sheltering
EARLY_EV	Evacuation successful
LATE_EV	No evacuation
HALF_EV	In the case wind direction north, Kakuda is evacuated but Minamisoma is not.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Wind speed
WDIR
Wind direction
PRECIP
Precipitation
Shelter
Population shel tering
EVAC
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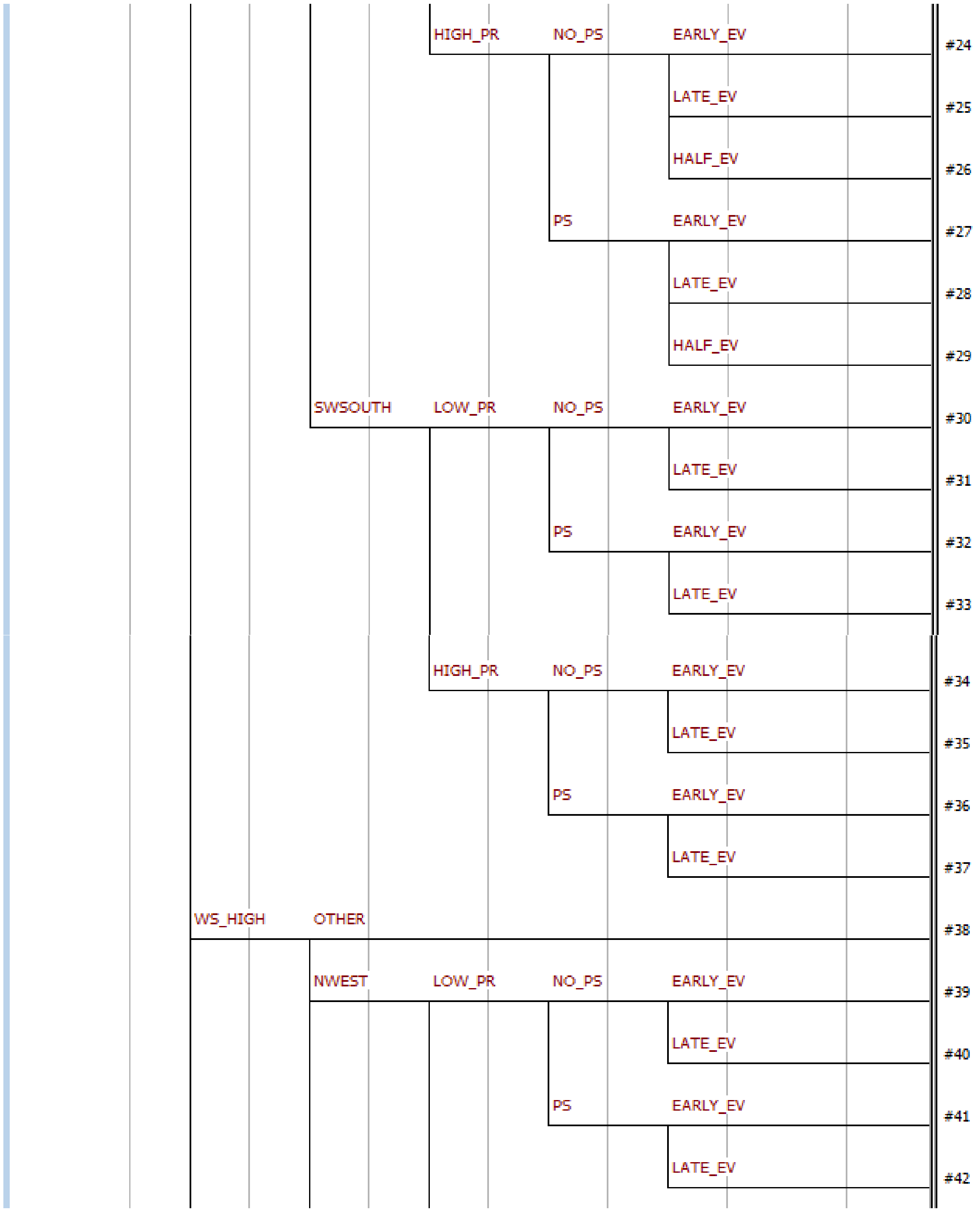
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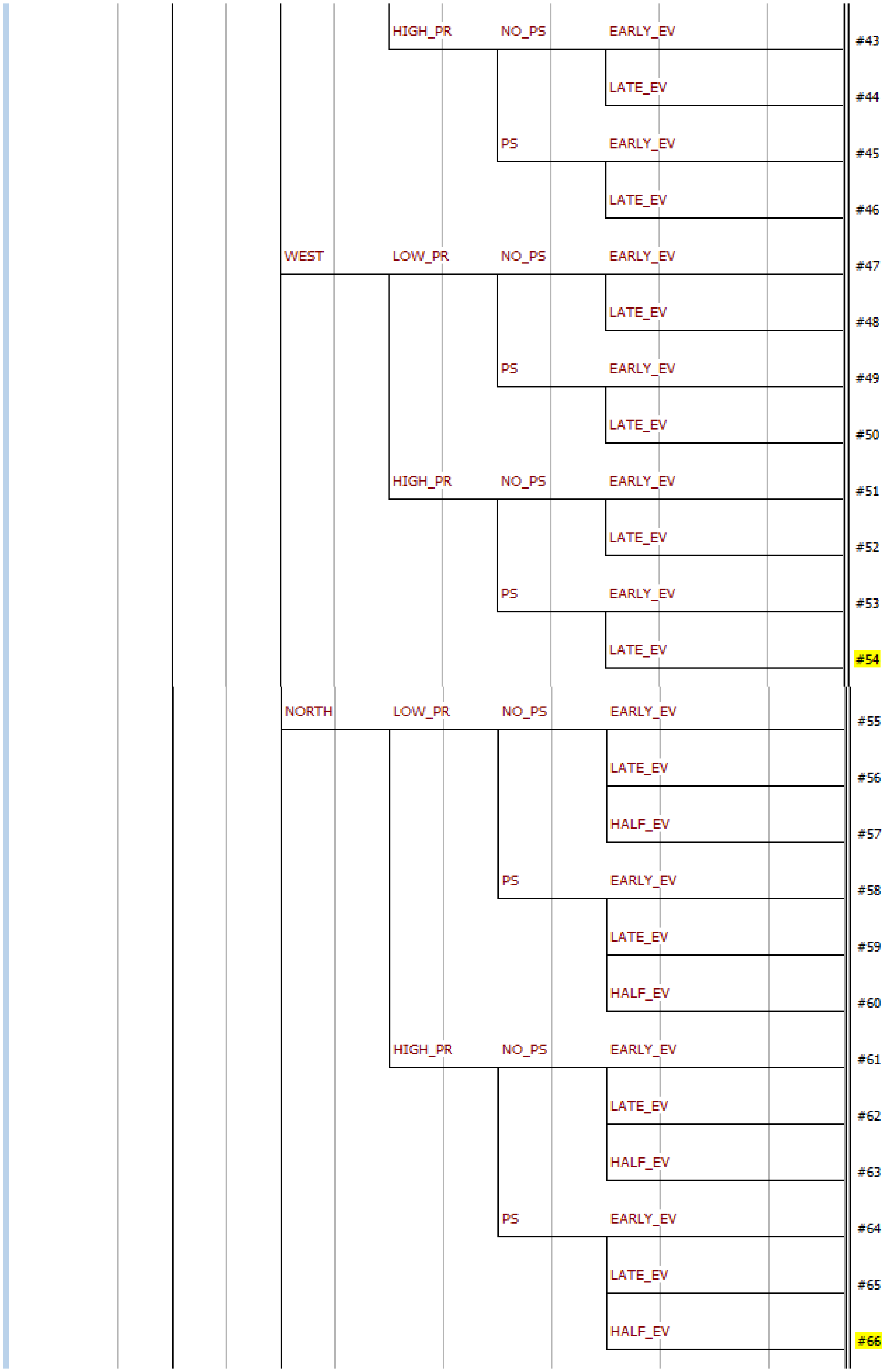
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HALF_EV
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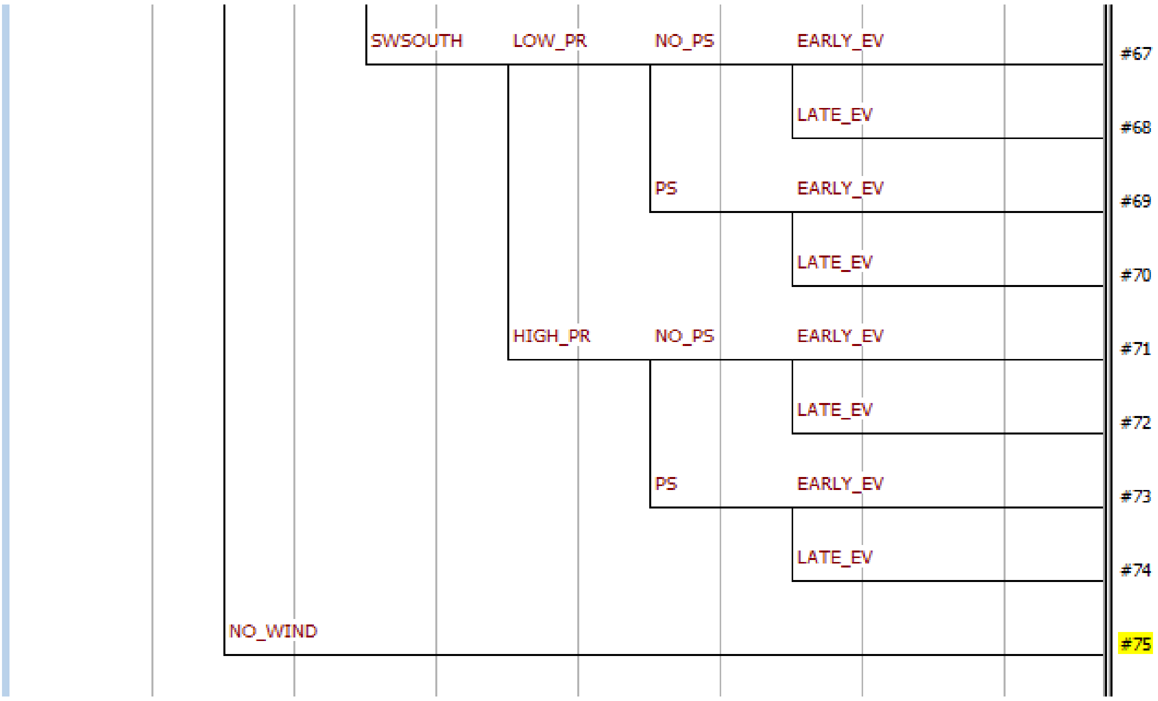

The initial section:

```
real cancers,
     pdose,
     ws,
     dist1,
     dist2,
     time1,
     time2,
     shfactor

boolean popshe1,
        rain,
        popshe2

string dir

source cancers

routine init
  BinFreq = 1
return

routine finish
  cancers = pdose*0.05
return

class dir
routine binner active
  ('NWest',   'Expo'),
  ('West',    'Expo'),
  ('North',   'Expo'),
  ('SWSouth', 'Expo'),
```

```
  ('Other',    'Other')
return
```

WSPEED section:

```
real wsh, wsl

routine init
  wsh = raneven(0.050185, 0.090185)
  wsl = raneven(0.176314116, 0.216314116)
return


function real WS_HIGH
  ws = 16*0.001*60*60
return wsh

function nil NO_WIND
  ws = 0
  dir = 'Other'
return nil

function real WS_LOW
  ws = 8*0.001*60*60
return wsl
```

WDIR section

```
real nw, w, n, sws

routine init
  nw = raneven(0.018, 0.058)
  w = raneven(0.007, 0.047)
  n = raneven(0.094, 0.134)
  sws = raneven(0.077, 0.117)
return

function real NWEST
  dist1 = 64
  dist2 = 0
  dir = 'NWest'
return nw

function real WEST
  dist1 = 56
  dist2 = 0
  dir = 'West'
return w

function real NORTH
  dist1 = 27
  dist2 = 58
  dir = 'North'
return n

function real SWSOUTH
  dist1 = 48
```

```
  dist2 = 0
  dir = 'SWSouth'
return sws

function nil OTHER
  dist1 = 0
  dist2 = 0
  dir = 'Other'
  pdose = 0
return nil
```

PRECIP section

```
real hp

routine init
  hp = raneven(0.158, 0.358)
return

function real HIGH_PR
  rain = true
return hp

function nil LOW_PR
  rain = false
return nil
```

SHELTER section

```
real sp, sf

routine init
  sp = raneven(0.6, 1)
  sf = raneven(0.5, 0.9)
return

function real PS
  time1 = dist1/ws
  time2 = dist2/ws
  shfactor = sf
return sp

function nil NO_PS
  time1 = dist1/ws
  time2 = dist2/ws
  shfactor = 1
return nil
```

EVAC section

```
real l1, l2

function nil LATE_EV
  if samestr(dir, 'NWest') then
  begin
     if rain then
     begin
```

```
      if more(ws, 10) then
      begin
        pdose = shfactor*3528
      end
      else
      begin
        pdose = shfactor*3822
      end
    end
    else
    begin
      if more(ws, 10) then
      begin
        pdose = shfactor*4410
      end
      else
      begin
        pdose = shfactor*6174
      end
    end
  end
  else if samestr(dir, 'West') then
  begin
    if rain then
    begin
      if more(ws, 10) then
      begin
        pdose = shfactor*5408
      end
      else
      begin
        pdose = shfactor*5746
      end
    end
    else
    begin
      if more(ws, 10) then
      begin
        pdose = shfactor*6422
      end
      else
      begin
        pdose = shfactor*8788
      end
    end
  end
  else if samestr(dir, 'North') then
  begin
    if rain then
    begin
      if more(ws, 10) then
      begin
        pdose = shfactor*(3408+465)
      end
      else
      begin
```

```
        pdose = shfactor*(4828+496)
      end
    end
    else
    begin
      if more(ws, 10) then
      begin
        pdose = shfactor*(3692+558)
      end
      else
      begin
        pdose = shfactor*(5822+775)
      end
    end
  end
  else if samestr(dir, 'SWSouth') then
  begin
    if rain then
    begin
      if more(ws, 10) then
      begin
        pdose = shfactor*6900
      end
      else
      begin
        pdose = shfactor*8280
      end
    end
    else
    begin
      if more(ws, 10) then
      begin
        pdose = shfactor*8280
      end
      else
      begin
        pdose = shfactor*11385
      end
    end
  end
return nil

function real EARLY_EV
  l1 = time1/72
  pdose = 0
return l1

function real HALF_EV
  l2 = time2/72-time1/72
  if rain then
  begin
    if more(ws, 10) then
    begin
      pdose = shfactor*3408
    end
    else
```

```
      begin
        pdose = shfactor*4828
      end
    end
    else
    begin
      if more(ws, 10) then
      begin
        pdose = shfactor*3692
      end
      else
      begin
        pdose = shfactor*5822
      end
    end
return l2
```