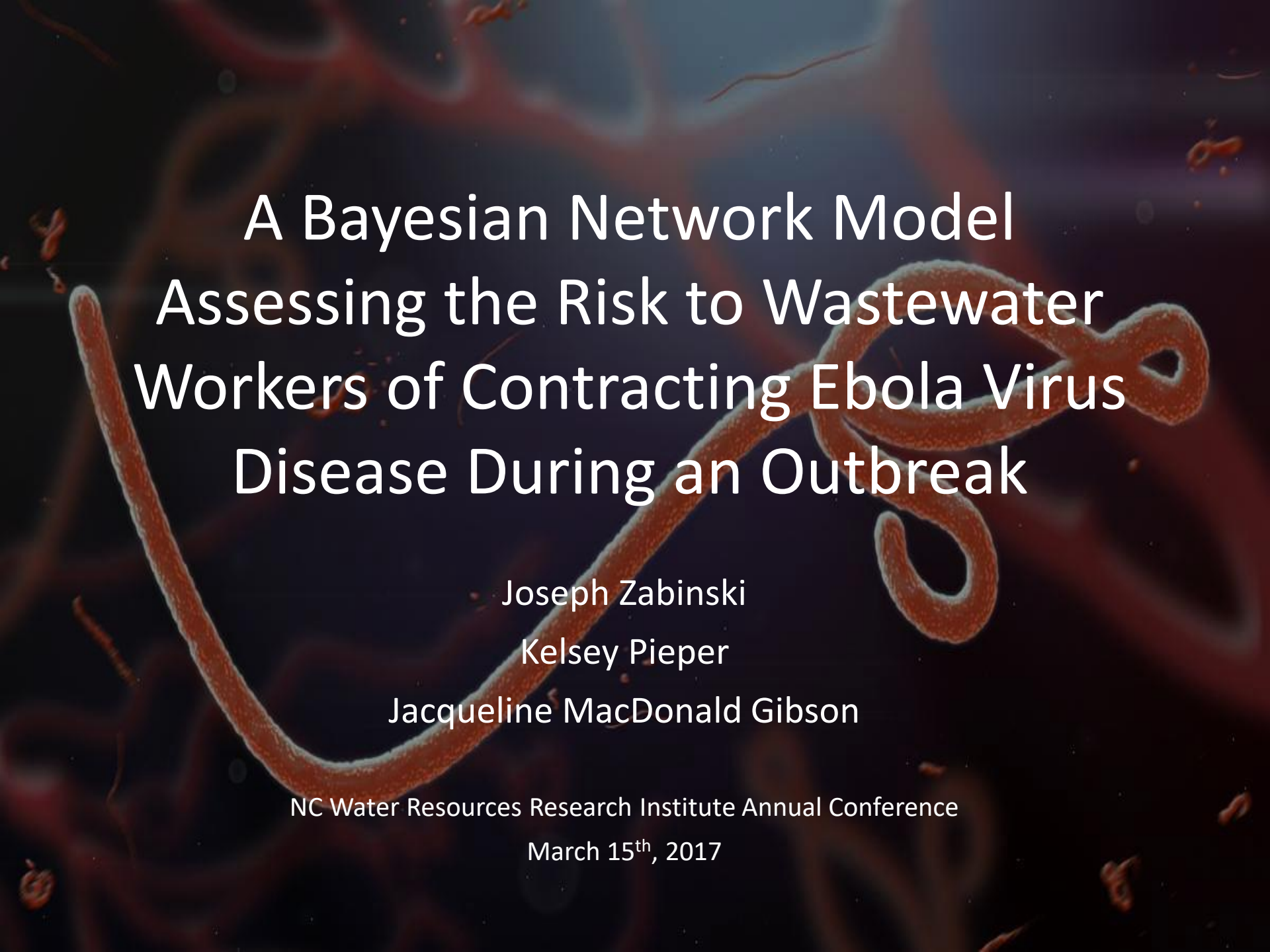


A Bayesian Network Model Assessing the Risk to Wastewater Workers of Contracting Ebola Virus Disease During an Outbreak

Joseph Zabinski

Kelsey Pieper

Jacqueline MacDonald Gibson

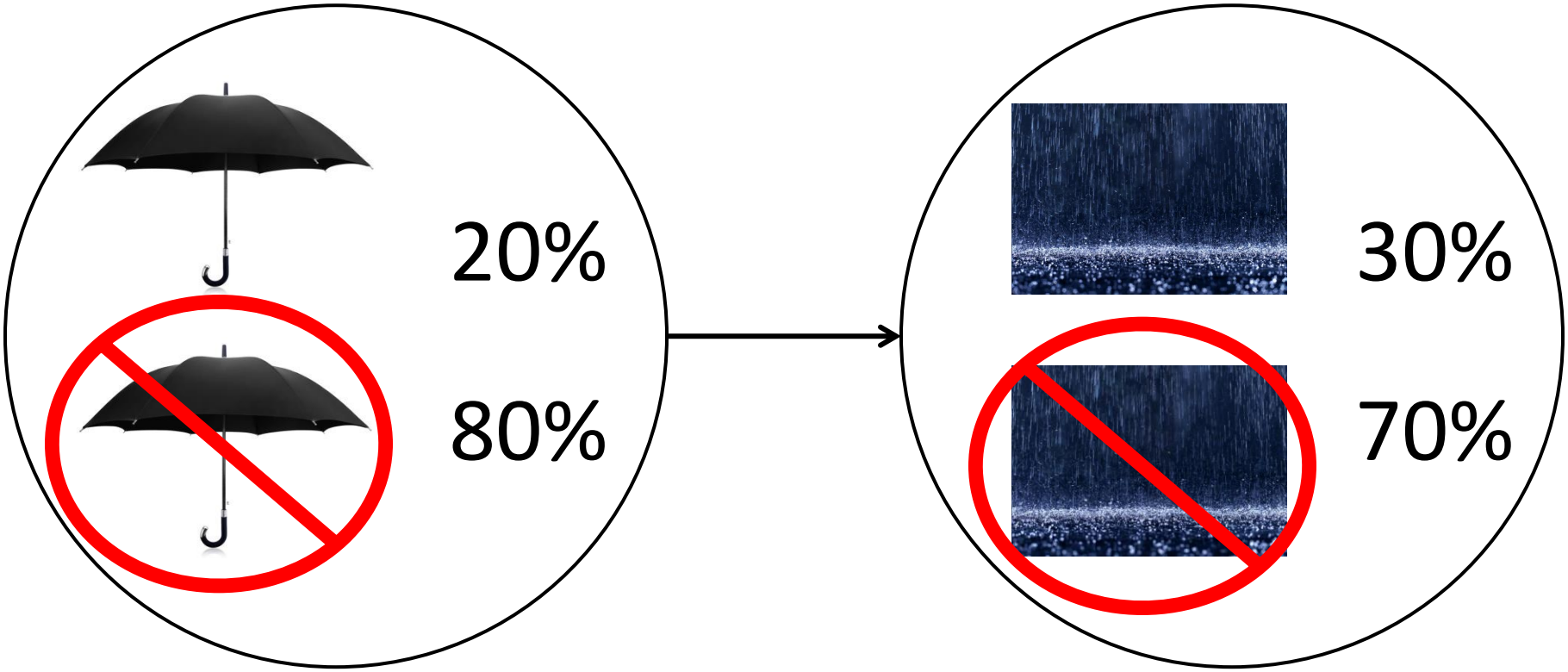
NC Water Resources Research Institute Annual Conference

March 15th, 2017

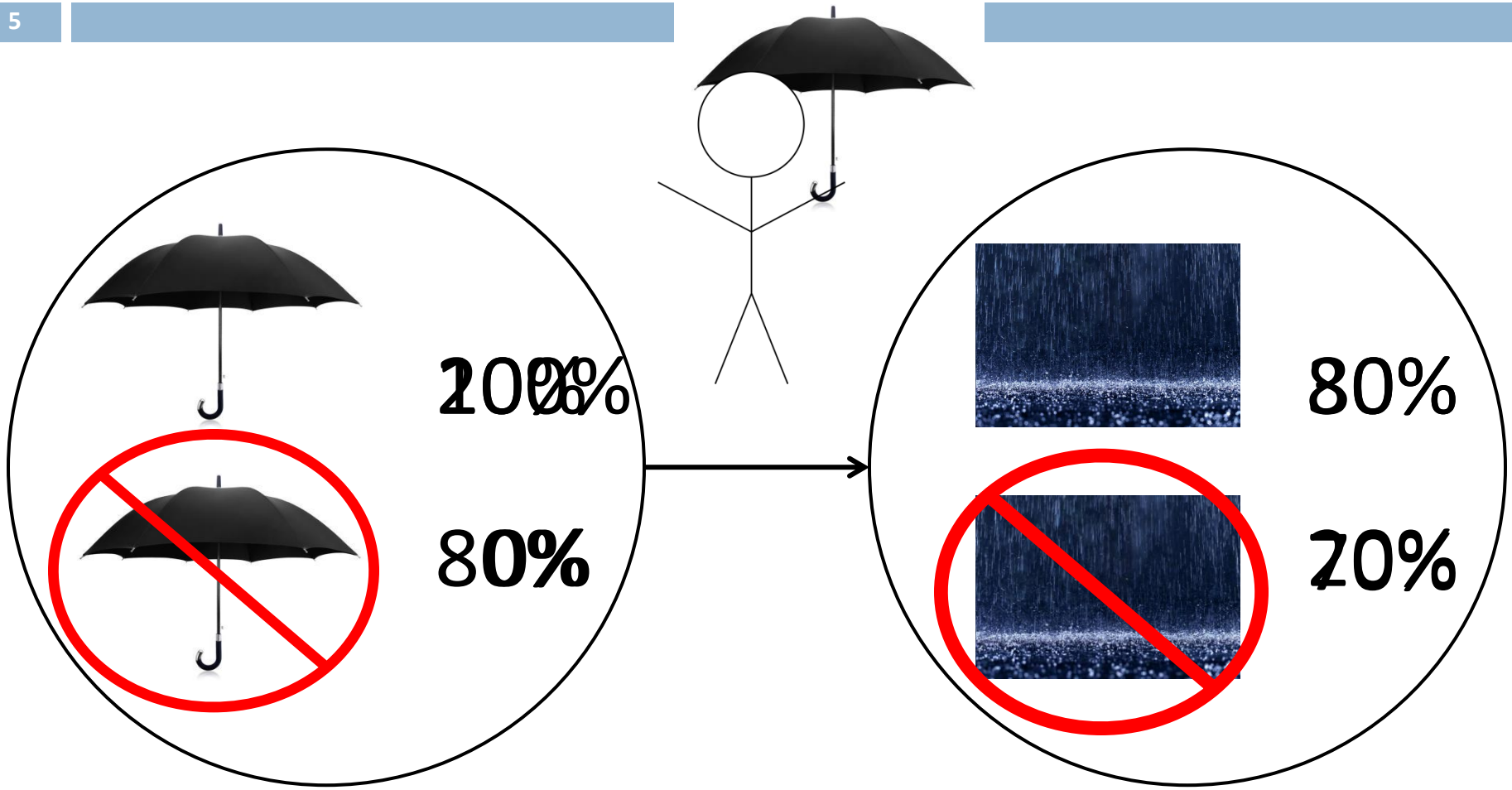
What’s Bayesian updating?

What’s Bayesian updating?

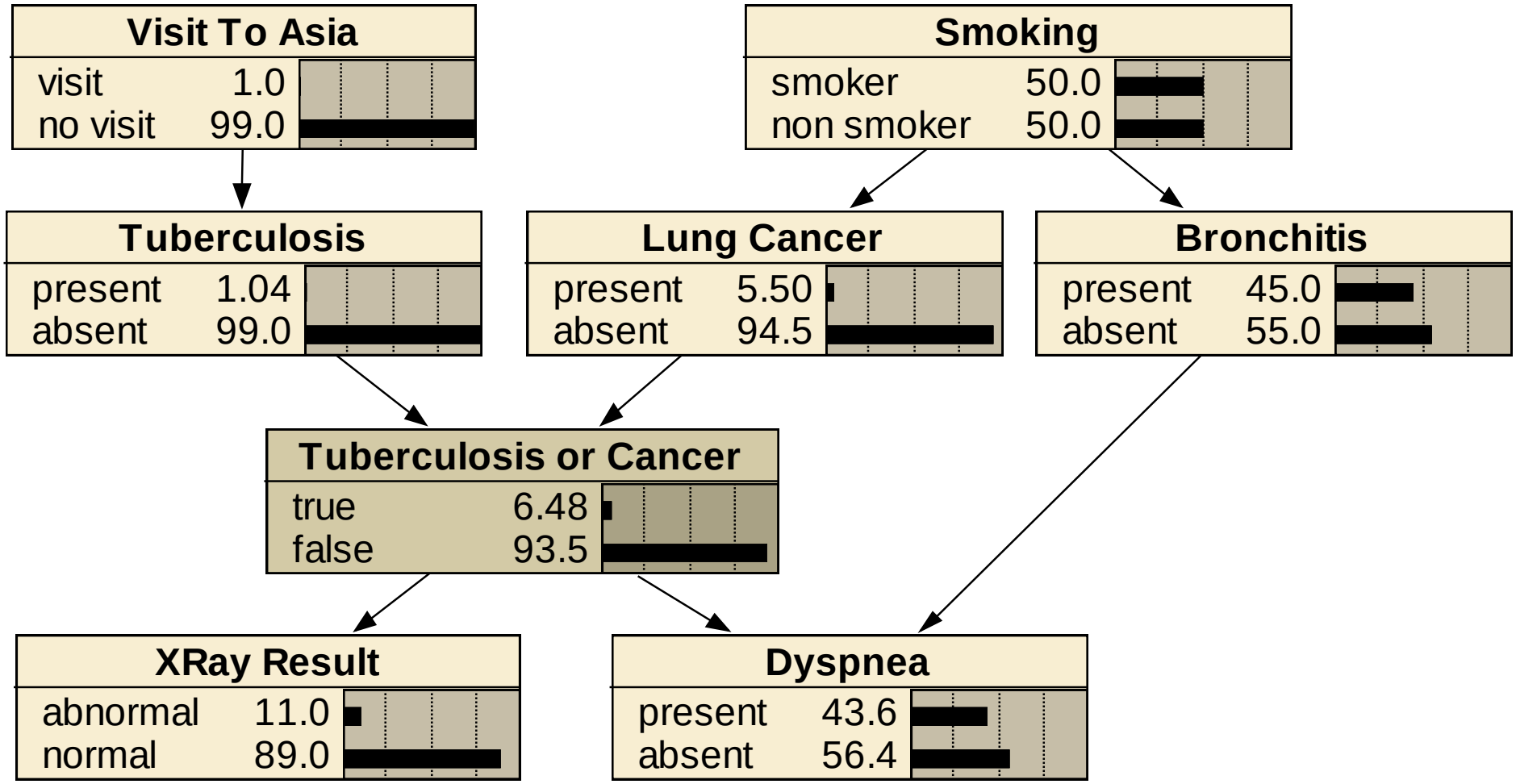
What's a Bayesian network?



What's a Bayesian network?

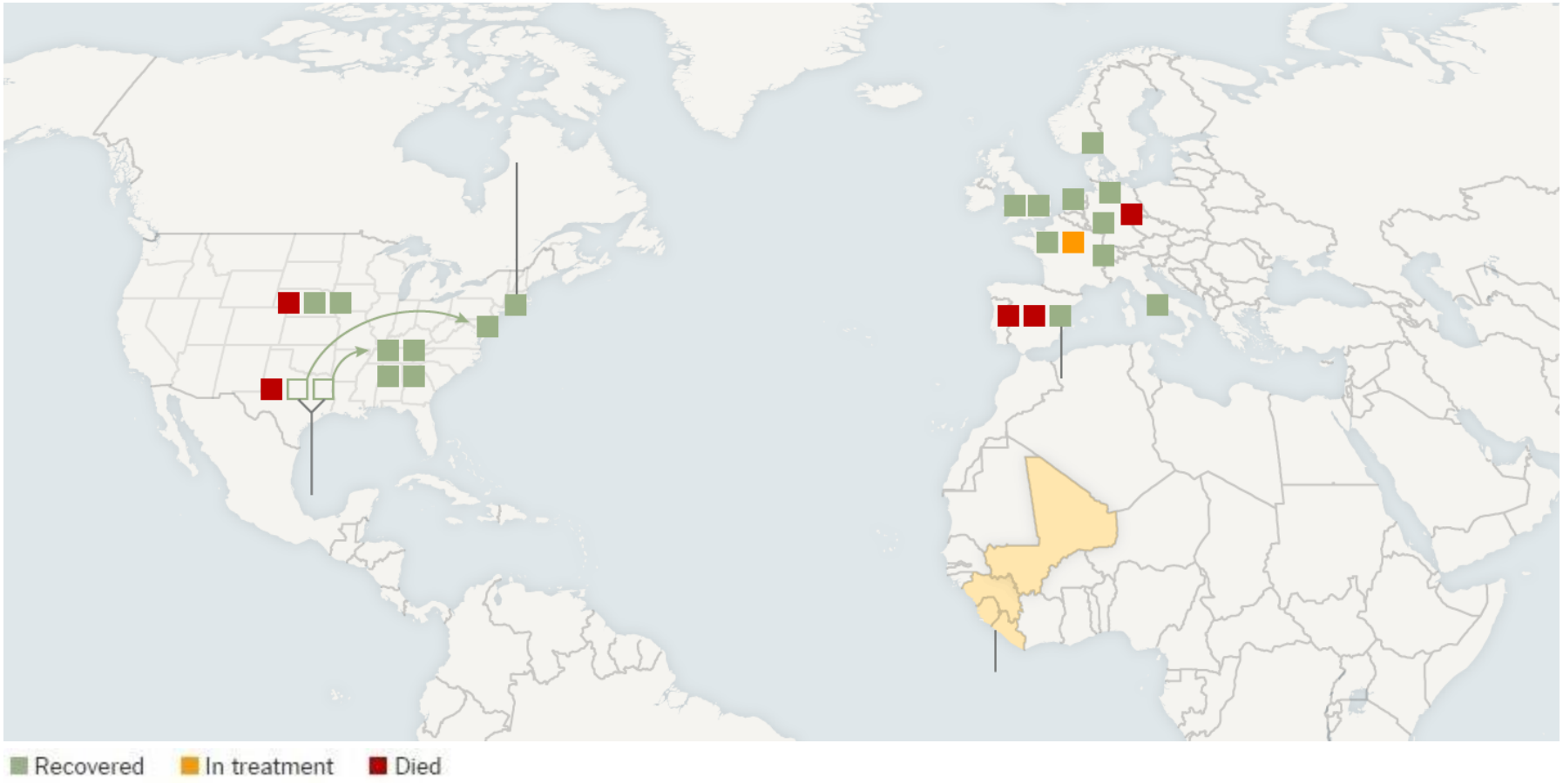


BN example: medical diagnostics



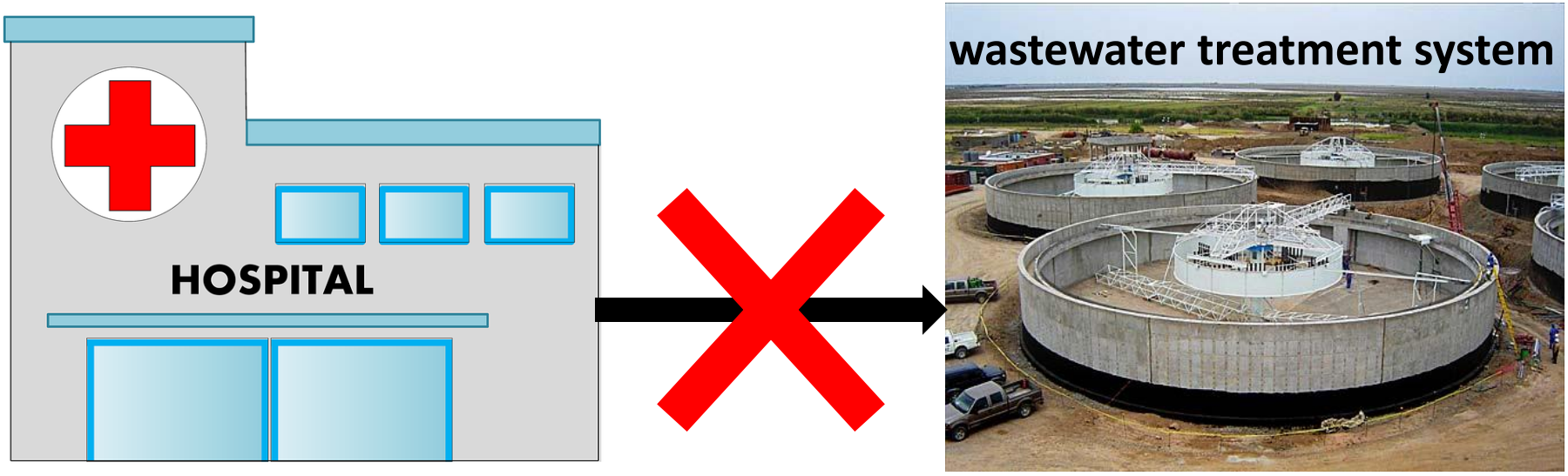
Netica BBN Library

2014 Ebola outbreak



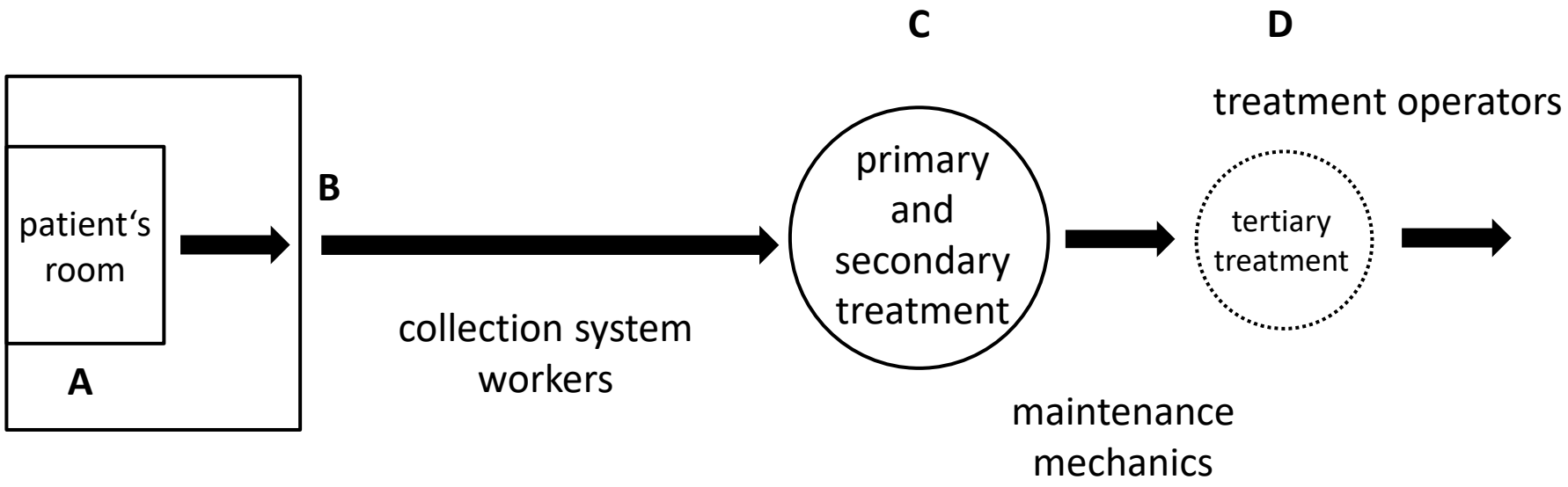
New York Times, 2014

Risk to wastewater workers?

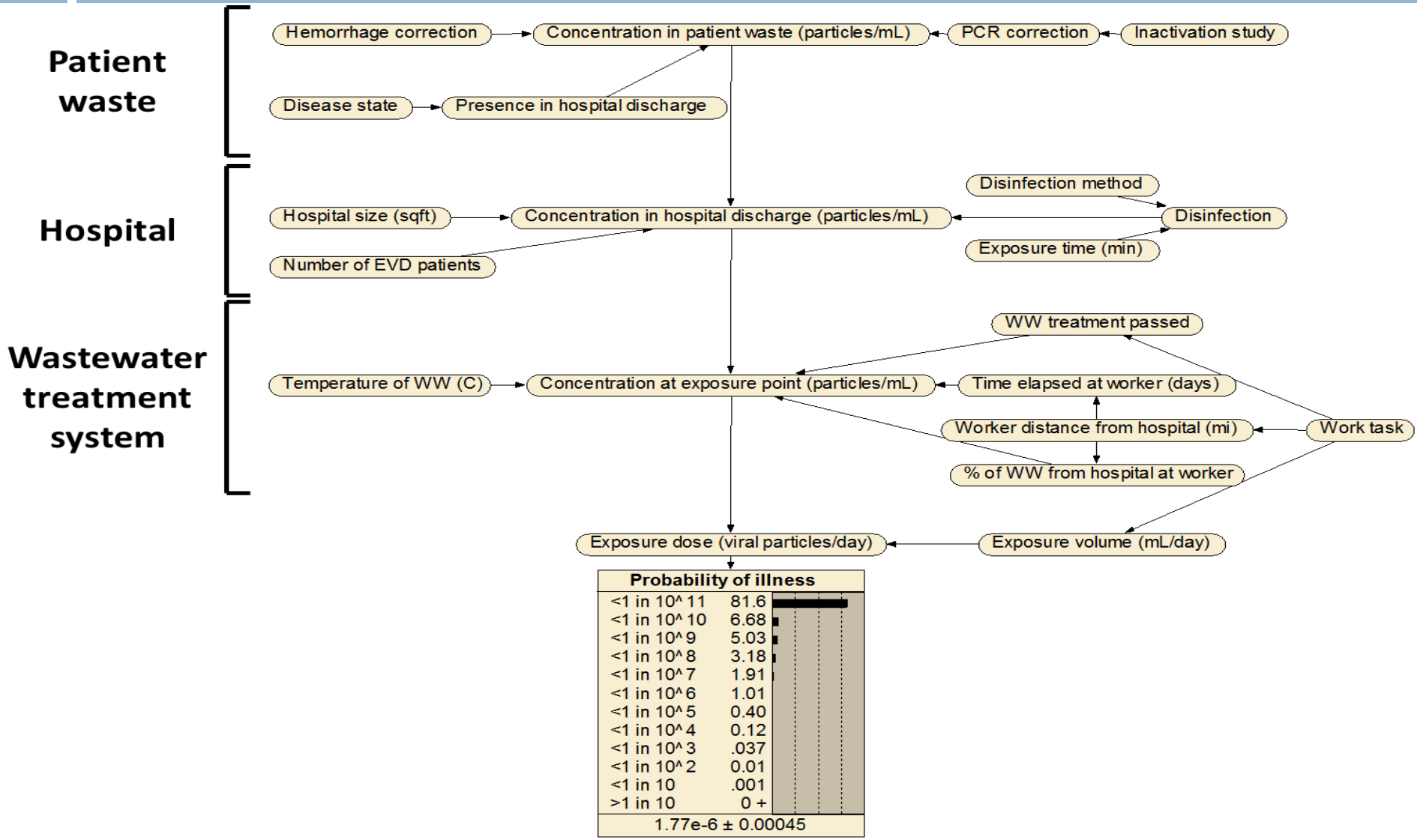


- need for assessment of risk to wastewater workers
- need to understand risk mitigation options

Conceptual model



Bayesian network model

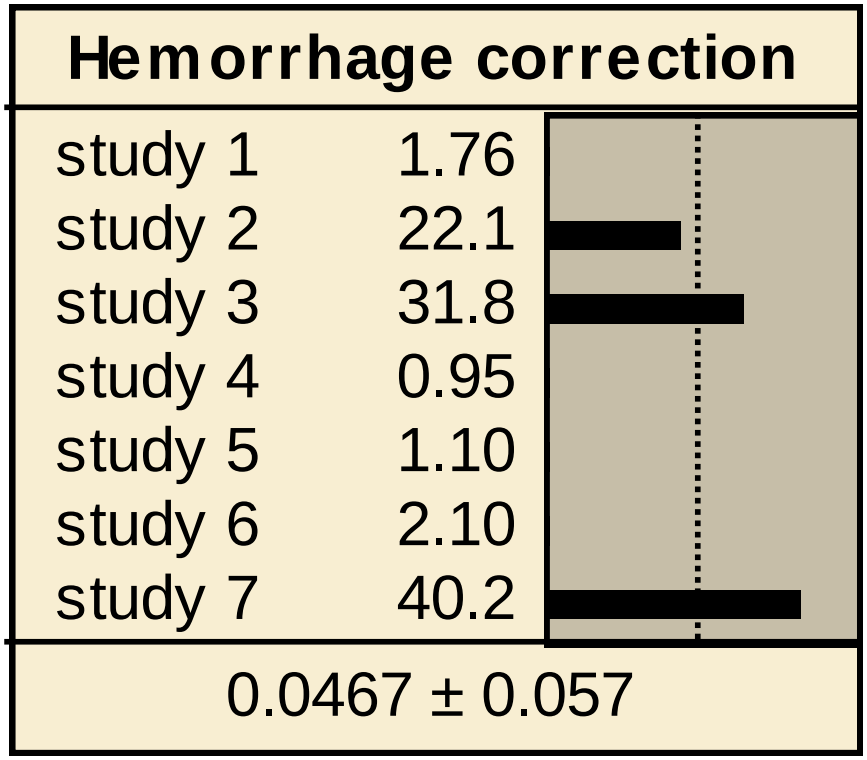


Highlight 1: hemorrhaging

Will the patient experience gastrointestinal hemorrhaging?

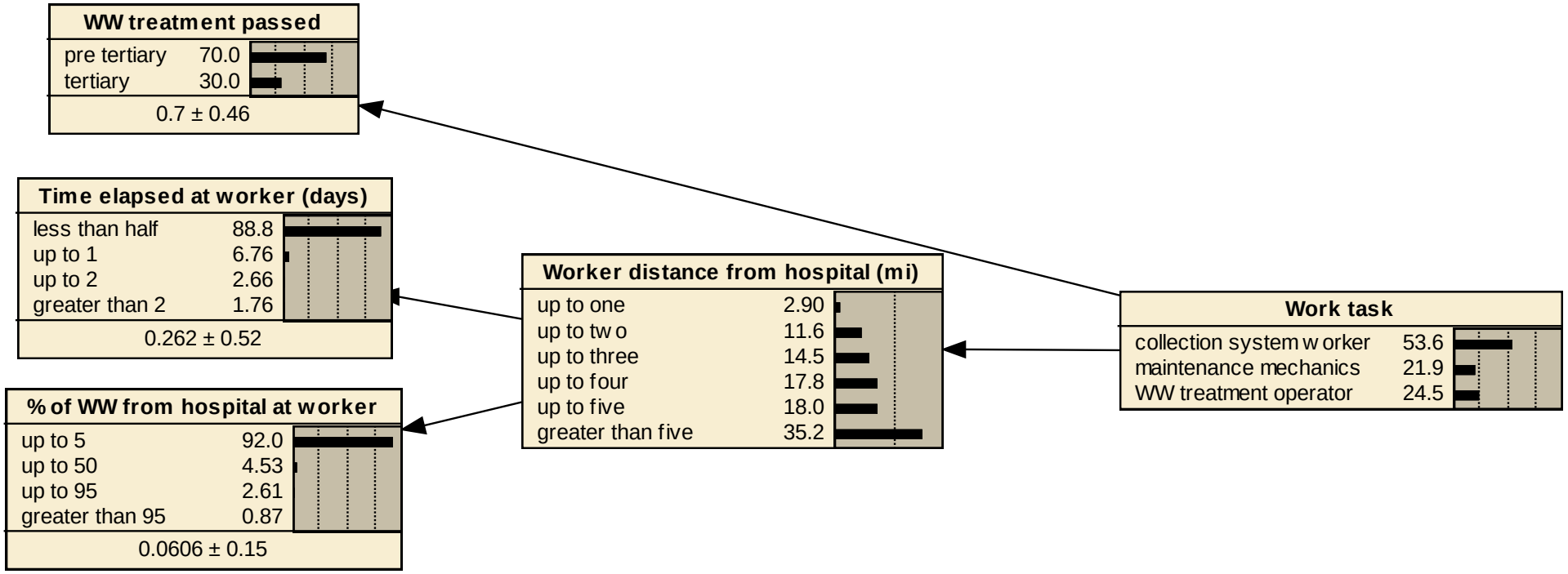
Study	Number of Ebola patients	Number with GI hemorrhaging	Probability of GI hemorrhaging	Study weight
1	37	9	24.3%	1.8%
2	464	19	4.1%	22.1%
3	666	6	0.9%	31.8%
4	20	5	25.0%	1.0%
5	23	10	43.5%	1.1%
6	44	1	2.3%	2.1%
7	843	48	6.7%	40.2%

Highlight 1: hemorrhage correction

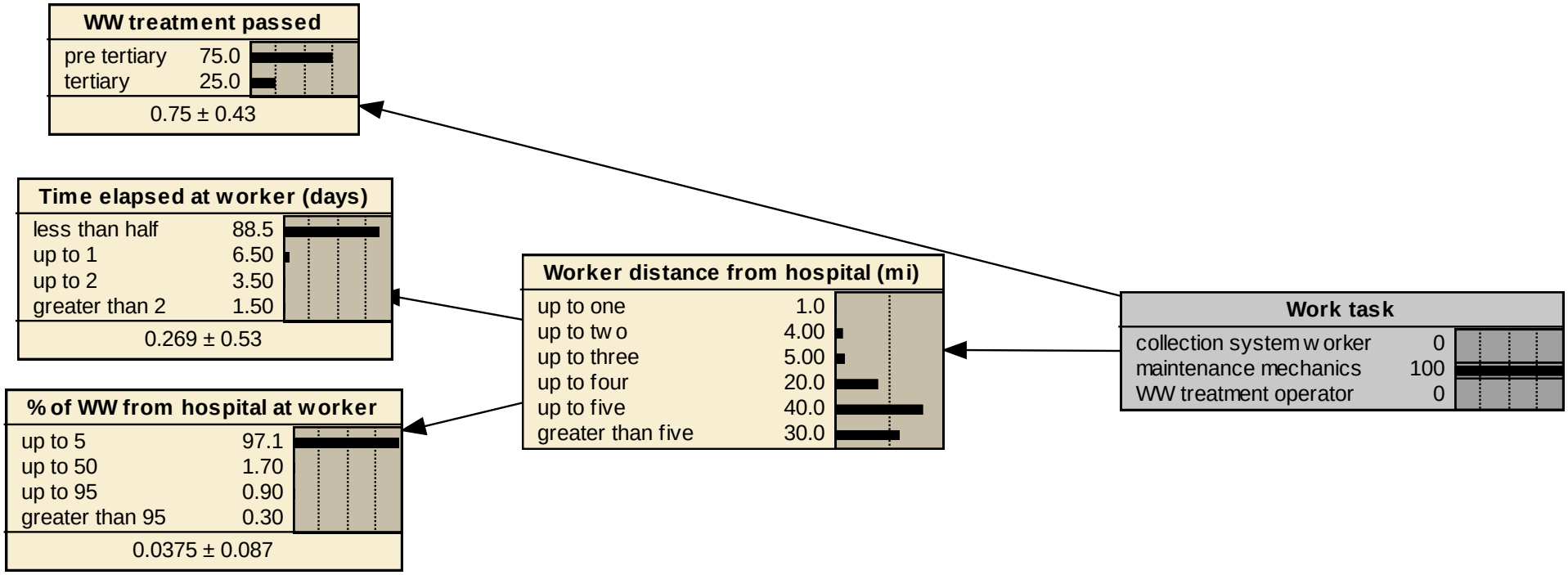


Highlight 2: worker data

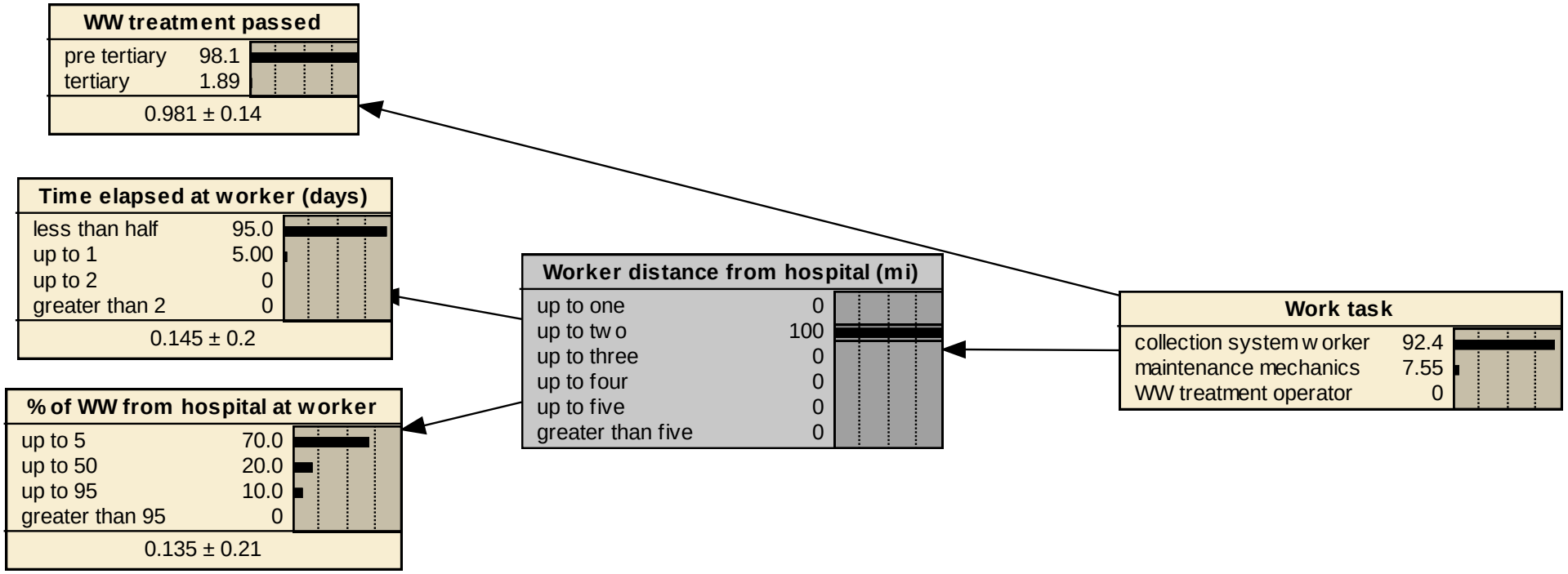
How do we specify worker's exposure point?



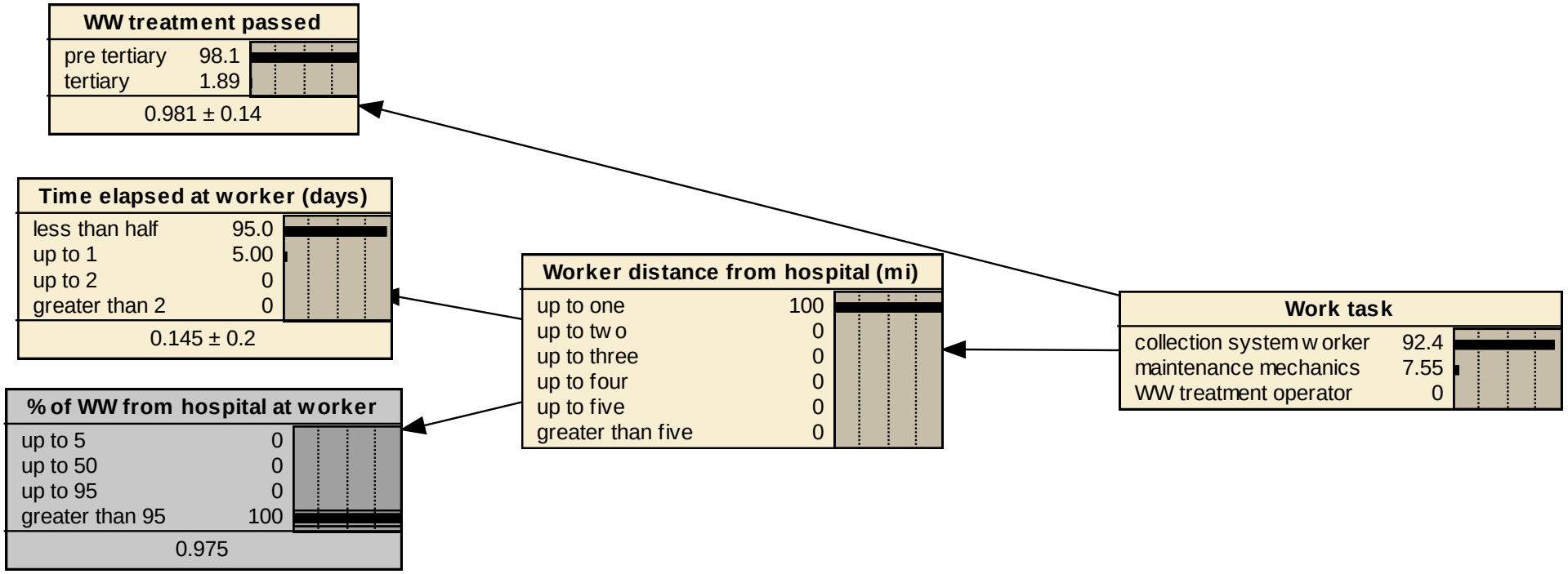
Highlight 2: worker data



Highlight 2: worker data

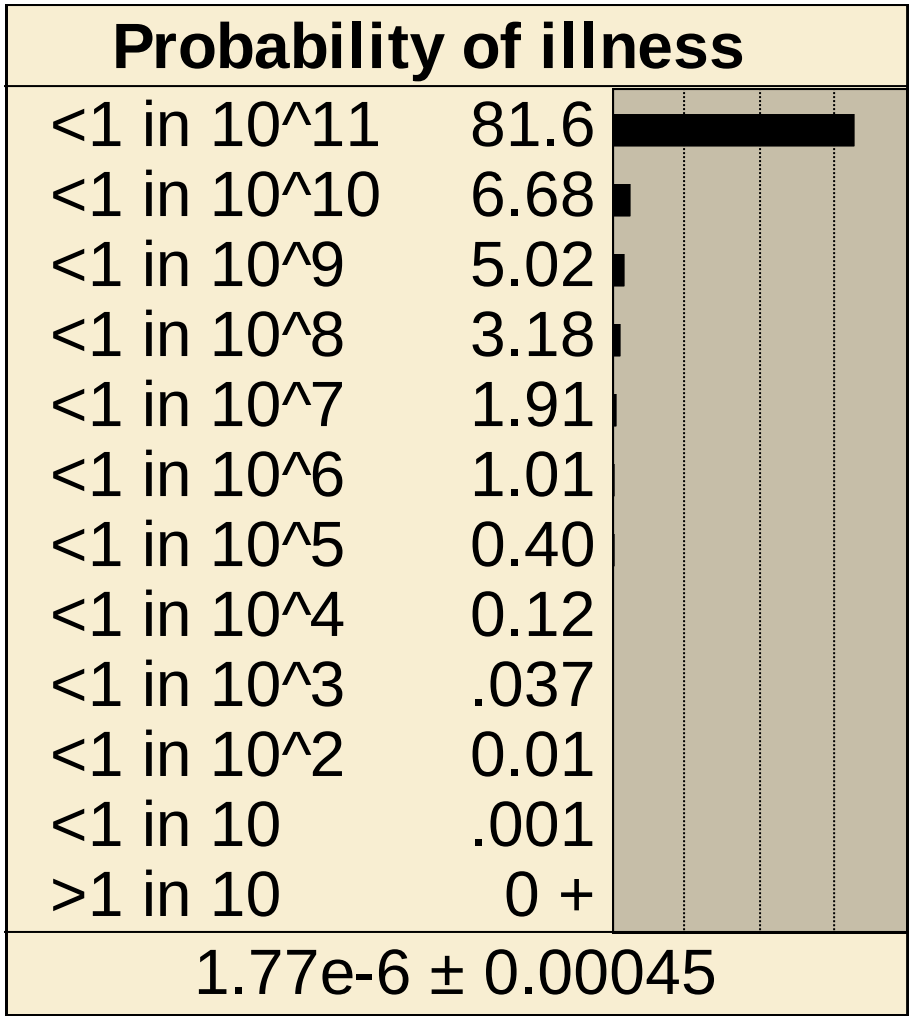


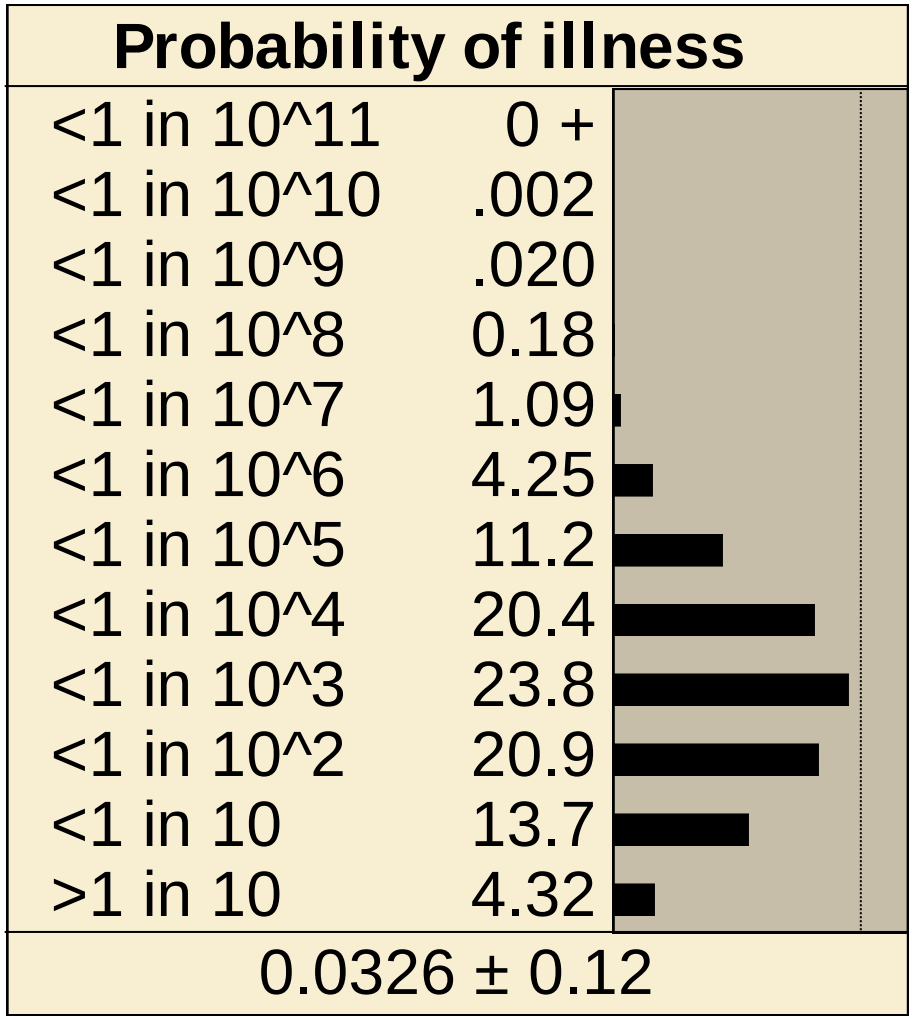
Highlight 2: worker data

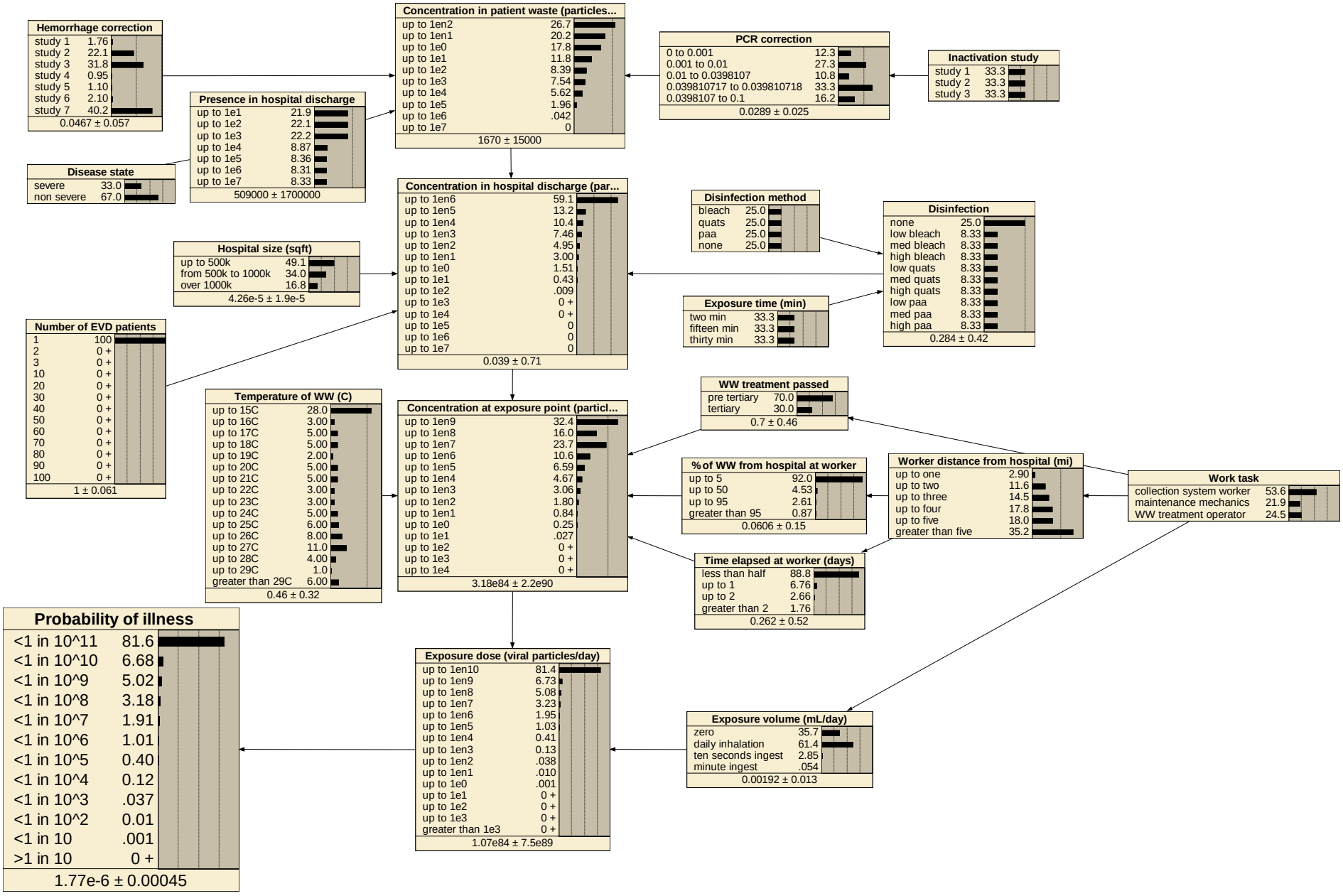


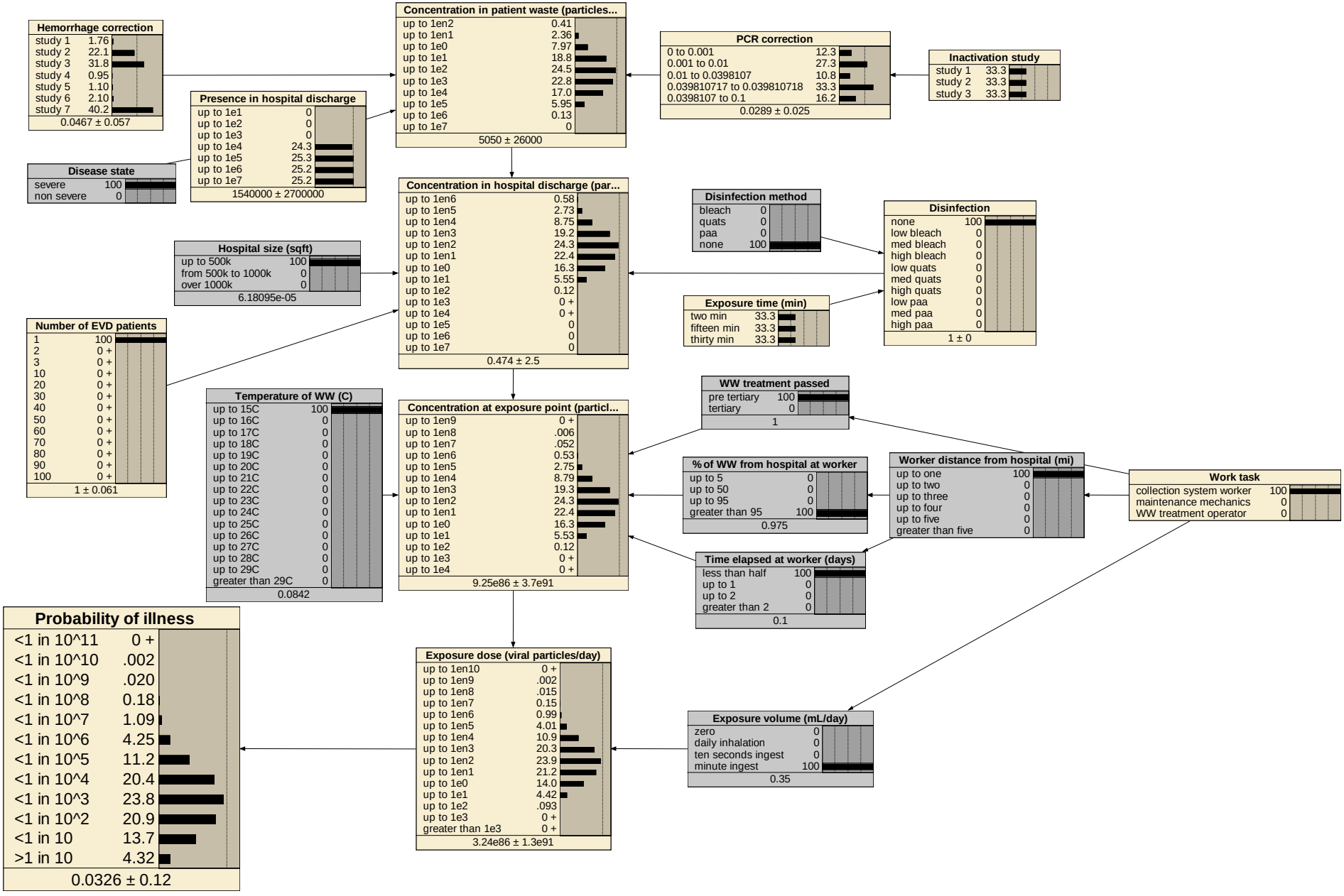
Highlight 3: outputs

How do we communicate risk results?



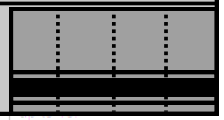



Hemorrhage correction
study 1 1.76
study 2 22.1
study 3 31.8
study 4 0.95
study 5 1.10
study 6 2.10
study 7 40.2
0.0467 ± 0.057
Concentration in patient waste (particles...
up to 1en2 26.7
up to 1en1 20.2
up to 1e0 17.8
up to 1e1 11.8
up to 1e2 8.39
up to 1e3 7.54
up to 1e4 5.62
up to 1e5 1.96
up to 1e6 .042
up to 1e7 0
1670 ± 15000
PCR correction
0 to 0.001 12.3
0.001 to 0.01 27.3
0.01 to 0.0398107 10.8
0.039810717 to 0.039810718 33.3
0.0398107 to 0.1 16.2
0.0289 ± 0.025
Inactivation study
study 1 33.3
study 2 33.3
study 3 33.3
Presence in hospital discharge
up to 1e1 21.9
up to 1e2 22.1
up to 1e3 22.2
up to 1e4 8.87
up to 1e5 8.36
up to 1e6 8.31
up to 1e7 8.33
509000 ± 1700000
Disease state
severe 33.0
non severe 67.0
Concentration in hospital discharge (par...
up to 1en6 59.1
up to 1en5 13.2
up to 1en4 10.4
up to 1en3 7.46
up to 1en2 4.95
up to 1en1 3.00
up to 1e0 1.51
up to 1e1 0.43
up to 1e2 .009
up to 1e3 0 +
up to 1e4 0 +
up to 1e5 0
up to 1e6 0
up to 1e7 0
0.039 ± 0.71
Disinfection method
bleach 25.0
quats 25.0
paa 25.0
none 25.0
Disinfection
none 25.0
low bleach 8.33
med bleach 8.33
high bleach 8.33
low quats 8.33
med quats 8.33
high quats 8.33
low paa 8.33
med paa 8.33
high paa 8.33
0.284 ± 0.42
Exposure time (min)
two min 33.3
fifteen min 33.3
thirty min 33.3
Hospital size (sqft)
up to 500k 49.1
from 500k to 1000k 34.0
over 1000k 16.8
4.26e-5 ± 1.9e-5
Number of EVD patients
1 100
2 0 +
3 0 +
10 0 +
20 0 +
30 0 +
40 0 +
50 0 +
60 0 +
70 0 +
80 0 +
90 0 +
100 0 +
1 ± 0.061
Temperature of WW (C)
up to 15C 28.0
up to 16C 3.00
up to 17C 5.00
up to 18C 5.00
up to 19C 2.00
up to 20C 5.00
up to 21C 5.00
up to 22C 3.00
up to 23C 3.00
up to 24C 5.00
up to 25C 6.00
up to 26C 8.00
up to 27C 11.0
up to 28C 4.00
up to 29C 1.0
greater than 29C 6.00
0.46 ± 0.32
Concentration at exposure point (particl...
up to 1en9 32.4
up to 1en8 16.0
up to 1en7 23.7
up to 1en6 10.6
up to 1en5 6.59
up to 1en4 4.67
up to 1en3 3.06
up to 1en2 1.80
up to 1en1 0.84
up to 1e0 0.25
up to 1e1 .027
up to 1e2 0 +
up to 1e3 0 +
up to 1e4 0 +
3.18e84 ± 2.2e90
WW treatment passed
pre tertiary 70.0
tertiary 30.0
0.7 ± 0.46
%of WW from hospital at worker
up to 5 92.0
up to 50 4.53
up to 95 2.61
greater than 95 0.87
0.0606 ± 0.15
Worker distance from hospital (mi)
up to one 2.90
up to two 11.6
up to three 14.5
up to four 17.8
up to five 18.0
greater than five 35.2
Work task
collection system worker 53.6
maintenance mechanics 21.9
WW treatment operator 24.5
Time elapsed at worker (days)
less than half 88.8
up to 1 6.76
up to 2 2.66
greater than 2 1.76
0.262 ± 0.52
Probability of illness
<1 in 10^11 81.6
<1 in 10^10 6.68
<1 in 10^9 5.02
<1 in 10^8 3.18
<1 in 10^7 1.91
<1 in 10^6 1.01
<1 in 10^5 0.40
<1 in 10^4 0.12
<1 in 10^3 .037
<1 in 10^2 0.01
<1 in 10 .001
>1 in 10 0 +
1.77e-6 ± 0.00045
Exposure dose (viral particles/day)
up to 1en10 81.4
up to 1en9 6.73
up to 1en8 5.08
up to 1en7 3.23
up to 1en6 1.95
up to 1en5 1.03
up to 1en4 0.41
up to 1en3 0.13
up to 1en2 .038
up to 1en1 .010
up to 1e0 .001
up to 1e1 0 +
up to 1e2 0 +
up to 1e3 0 +
greater than 1e3 0 +
1.07e84 ± 7.5e89
Exposure volume (mL/day)
zero 35.7
daily inhalation 61.4
ten seconds ingest 2.85
minute ingest .054
0.00192 ± 0.013


Hemorrhage correction
study 1 1.76
study 2 22.1
study 3 31.8
study 4 0.95
study 5 1.10
study 6 2.10
study 7 40.2
0.0467 ± 0.057
Concentration in patient waste (particles...
up to 1en2 0.41
up to 1en1 2.36
up to 1e0 7.97
up to 1e1 18.8
up to 1e2 24.5
up to 1e3 22.8
up to 1e4 17.0
up to 1e5 5.95
up to 1e6 0.13
up to 1e7 0
5050 ± 26000
PCR correction
0 to 0.001 12.3
0.001 to 0.01 27.3
0.01 to 0.0398107 10.8
0.039810717 to 0.039810718 33.3
0.0398107 to 0.1 16.2
0.0289 ± 0.025
Inactivation study
study 1 33.3
study 2 33.3
study 3 33.3
Presence in hospital discharge
up to 1e1 0
up to 1e2 0
up to 1e3 0
up to 1e4 24.3
up to 1e5 25.3
up to 1e6 25.2
up to 1e7 25.2
1540000 ± 2700000
Disease state
severe 100
non severe 0
Concentration in hospital discharge (par...
up to 1en6 0.58
up to 1en5 2.73
up to 1en4 8.75
up to 1en3 19.2
up to 1en2 24.3
up to 1en1 22.4
up to 1e0 16.3
up to 1e1 5.55
up to 1e2 0.12
up to 1e3 0 +
up to 1e4 0 +
up to 1e5 0
up to 1e6 0
up to 1e7 0
0.474 ± 2.5
Disinfection method
bleach 0
quats 0
paa 0
none 100
Disinfection
none 100
low bleach 0
med bleach 0
high bleach 0
low quats 0
med quats 0
high quats 0
low paa 0
med paa 0
high paa 0
1 ± 0
Hospital size (sqft)
up to 500k 100
from 500k to 1000k 0
over 1000k 0
6.18095e-05
Exposure time (min)
two min 33.3
fifteen min 33.3
thirty min 33.3
Number of EVD patients
1 100
2 0 +
3 0 +
10 0 +
20 0 +
30 0 +
40 0 +
50 0 +
60 0 +
70 0 +
80 0 +
90 0 +
100 0 +
1 ± 0.061
Temperature of WW (C)
up to 15C 100
up to 16C 0
up to 17C 0
up to 18C 0
up to 19C 0
up to 20C 0
up to 21C 0
up to 22C 0
up to 23C 0
up to 24C 0
up to 25C 0
up to 26C 0
up to 27C 0
up to 28C 0
up to 29C 0
greater than 29C 0
0.0842
WW treatment passed
pre tertiary 100
tertiary 0
1
Concentration at exposure point (particl...
up to 1en9 0 +
up to 1en8 .006
up to 1en7 .052
up to 1en6 0.53
up to 1en5 2.75
up to 1en4 8.79
up to 1en3 19.3
up to 1en2 24.3
up to 1en1 22.4
up to 1e0 16.3
up to 1e1 5.53
up to 1e2 0.12
up to 1e3 0 +
up to 1e4 0 +
9.25e86 ± 3.7e91
% of WW from hospital at worker
up to 5 0
up to 50 0
up to 95 0
greater than 95 100
0.975
Worker distance from hospital (mi)
up to one 100
up to two 0
up to three 0
up to four 0
up to five 0
greater than five 0
Work task
collection system worker 100
maintenance mechanics 0
WW treatment operator 0
Time elapsed at worker (days)
less than half 100
up to 1 0
up to 2 0
greater than 2 0
0.1
Probability of illness
<1 in 10^11 0 +
<1 in 10^10 .002
<1 in 10^9 .020
<1 in 10^8 0.18
<1 in 10^7 1.09
<1 in 10^6 4.25
<1 in 10^5 11.2
<1 in 10^4 20.4
<1 in 10^3 23.8
<1 in 10^2 20.9
<1 in 10 13.7
>1 in 10 4.32
0.0326 ± 0.12
Exposure dose (viral particles/day)
up to 1en10 0 +
up to 1en9 .002
up to 1en8 .015
up to 1en7 0.15
up to 1en6 0.99
up to 1en5 4.01
up to 1en4 10.9
up to 1en3 20.3
up to 1en2 23.9
up to 1en1 21.2
up to 1e0 14.0
up to 1e1 4.42
up to 1e2 .093
up to 1e3 0 +
greater than 1e3 0 +
3.24e86 ± 1.3e91
Exposure volume (mL/day)
zero 0
daily inhalation 0
ten seconds ingest 0
minute ingest 100
0.35

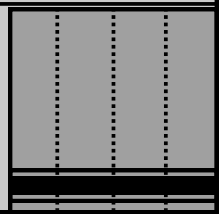
Disease state

severe	0
non severe	100



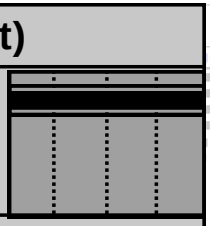
Disinfection method

bleach	0
quats	0
paa	0
none	100



Hospital size (sqft)

up to 500k	100
from 500k to 1000k	0
over 1000k	0



6.18095e-05

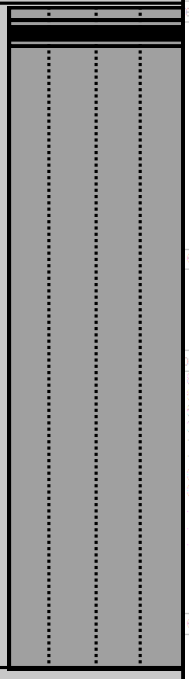
WW treatment passed

pre tertiary	100
tertiary	0

1

Temperature of WW (C)

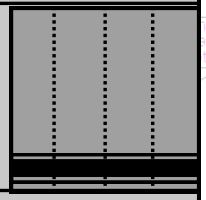
up to 15C	100
up to 16C	0
up to 17C	0
up to 18C	0
up to 19C	0
up to 20C	0
up to 21C	0
up to 22C	0
up to 23C	0
up to 24C	0
up to 25C	0
up to 26C	0
up to 27C	0
up to 28C	0
up to 29C	0
greater than 29C	0



0.0842

% of WW from hospital at worker

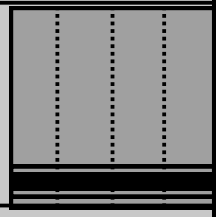
up to 5	0
up to 50	0
up to 95	0
greater than 95	100



0.975

Exposure volume (mL/day)

zero	0
daily inhalation	0
ten seconds ingest	0
minute ingest	100

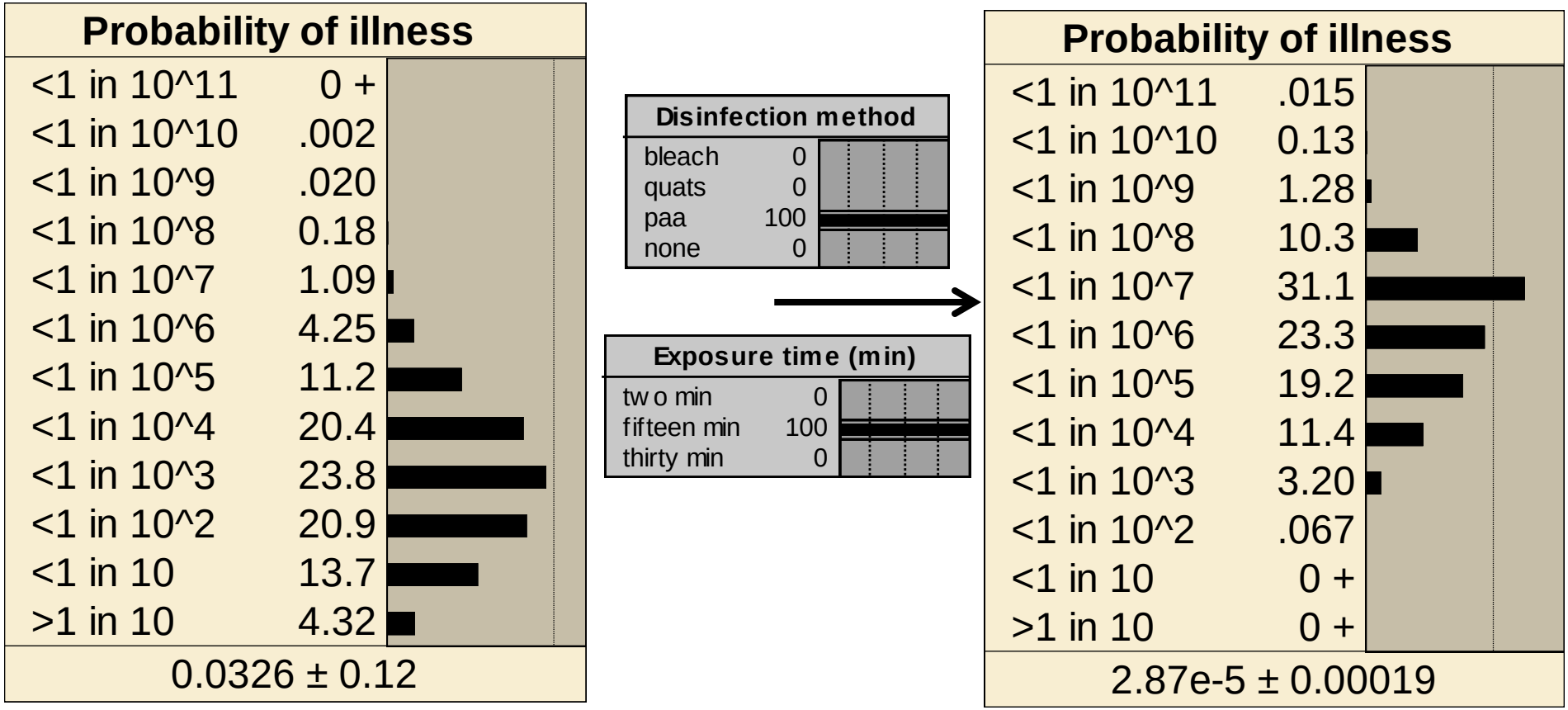


0.35

Results

- median daily risk (no specifications) : 6.1×10^{-12} (90% CI 1.0×10^{-12} –5.4×10^{-9})
- median daily risk (worst-case scenario): 5.8×10^{-4} (90% CI 8.8×10^{-7}–9.5×10^{-2})
- risk is greatest under ingestion scenarios
- disinfection and dilution have substantial impacts on risk

Decision support



BN conclusions

- Bayesian networks can incorporate many different factors to estimate risk
- can also detect key parameters affecting risk and simulate scenarios and treatment effects
- powerful decision support tool for risk managers

(for more – see *Risk Analysis* manuscript)

Thanks!

- Dr. Jacqueline MacDonald Gibson
- Dr. Kelsey Pieper
- Dr. Emanuele Sozzi
- Dr. Mark Sobsey
- Dr. Jamie Bartram
- Dr. Hannah Sassi & the Gerba research group (Arizona)
- Taylor Rycroft & the Haas research group (Drexel)
- Dr. Lisa Casanova
- Dr. Jade Mitchell
- Jason Waters & the City of Raleigh's Wastewater Treatment Utility
- Lola Olabode & WERF