Three Approaches To Pesticide Exposure Assessment: Integration, Aggregation, and Aggravation

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HS 1771

March 11, 1998

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37th Society of Toxicology Annual Meeting, Poster No. 203
March 1 - 5, 1998, Seattle, Washington
(Abstract Published in *Toxicological Sciences - The Toxicologist* 42:41)

ABSTRACT

Exposure assessment is part of the risk characterization process undertaken prior to the continued approval of the registration of a pesticide, despite the fact that submission of chemical-specific exposure data is not mandatory. This paper is an attempt to highlight and to demonstrate the impacts of three exposure assessment approaches on the risk characterization of economic poisons. Until the recent emergence of probabilistic analysis in exposure assessment, common practice has been to select conservative point estimates for the exposure scenario in question. This aggravation approach often results in an overestimation of the health risk involved, especially when multiple exposure pathways are considered. Although the concept of totaling pesticide exposures from all sources is not new, most regulatory agencies did not begin to implement this totaling or aggregation approach until after U.S. Congress passed the 1996 Food Quality Protection Act. Summing exposures from all sources may not be appropriate, however, since not all relevant exposure data are available and not all exposure events are to occur concurrently or with equal probability. The integration approach is one step beyond the current use of probabilistic analysis in pesticide exposure assessment. It takes multiple exposure pathways into consideration in performing the probabilistic analysis, at least to the extent feasible. The case study included here contrasts the exposure estimates calculated from using the integration approach with those from using the aggregation approach.

INTRODUCTION

As the case study in this paper also shows, on a single day a person may be exposed to a pesticide outdoors at the treatment site *and* later indoors at home. Although the concept of totaling pesticide exposures from all sources is not new, some regulatory agencies did not begin to implement this aggregation approach until after U.S. Congress passed the 1996 Food Quality Protection Act. The purpose of this case study is an attempt to highlight as well as to contrast the several available assessment approaches to totaling exposures from all sources. Whichever way we put it, there are basically two types of exposure estimation techniques or methods available from which two approaches to totaling human exposures can be made. *Aggravation* and *probabilistic analysis* are the two types of techniques currently in use for the estimation of human exposure to pesticides, whereas *aggregation* and *integration* are the two basic types of totaling exposure approaches available. Some researchers and this author even wanted to reduce the basic exposure assessment techniques and approaches further, as reflected in the title of this paper. The above various technical terms are restated mathematically in the panels that follow (and hence shall become clearer).

The case study presented here had its focus primarily on the application of a wood preservative to outdoor playground structures. For proprietary reasons, this wood preservative was *re*named as Ground-It. The active ingredient in Ground-It is an inorganic metal. This active ingredient is ubiquitous in our environment, such as in drinking water, ambient air, food, and cigarette smoke. In food, much of this active ingredient is in the organic form and, as such, is considered to be less toxic to humans.

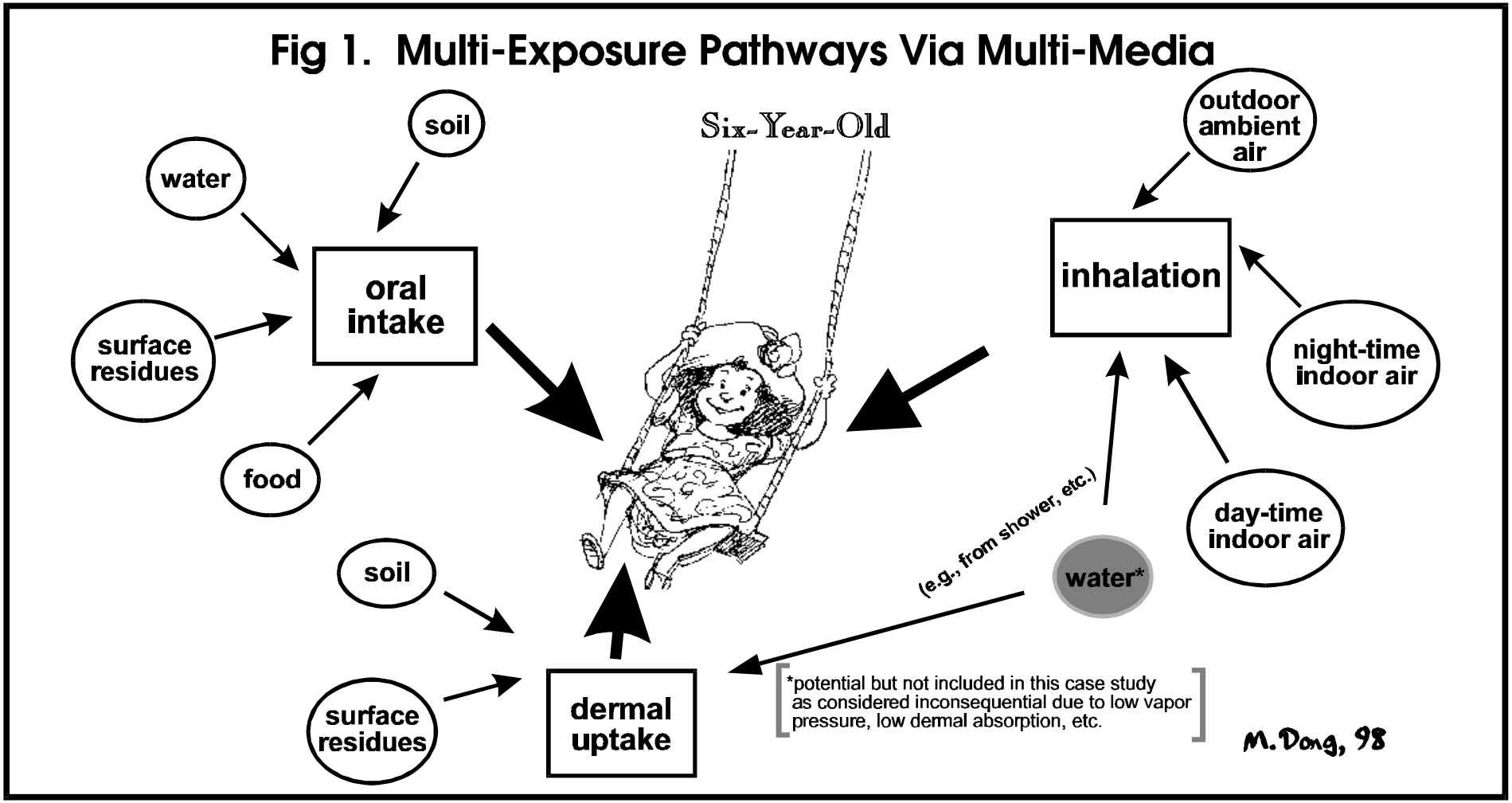
Fig 1. Multi-Exposure Pathways Via Multi-Media
Six-Year-Old
soil
water
oral intake
surface residues
food
outdoor ambient air
inhalation
night-time indoor air
day-time indoor air
(e.g., from shower, etc.)
water*
soil
surface residues
dermal uptake
*potential but not included in this case study as considered inconsequential due to low vapor pressure, low dermal absorption, etc.
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Fig 2. Basic Exposure Assessment Algorithms, per Activity

I. At Playground:

Dosage = inhalation [ambient air] + dermal uptake [soil] + dermal uptake [treated structure surface] + oral intake [soil] + oral intake [treated structure surface].

= {(ambient air level) x (hourly inhalation rate) x (duration) x (inhalation absorption) + (soil concentration) x (skin-soil loading per event) x (body surface portion for loading) x (dermal absorption) + (dislodgeables on treated surface) x (hourly dermal transfer rate) x (duration) x (dermal absorption) + (soil concentration) x (hourly soil ingestion rate) x (duration) x (oral absorption) + (dislodgeables on treated surface) x (hourly dermal transfer rate) x (body portion as hand surface) x (residues portion on hand for oral intake) x (duration) x (oral absorption)}/(body weight).

II. Outdoor (non-playground):

Dosage = inhalation [ambient air]. **(***dermal uptake or oral intake of soil residues in the non-treatment outdoor area was assumed to be negligible in order to provide a less complex assessment model for overall exposure.***)**

= {(ambient air level) x (hourly inhalation rate) x (duration) x (inhalation absorption)}/(body weight).

III. Indoor (day-time):

Dosage = inhalation [indoor air in a second-hand smoking area] + dietary [food] + drinking water.

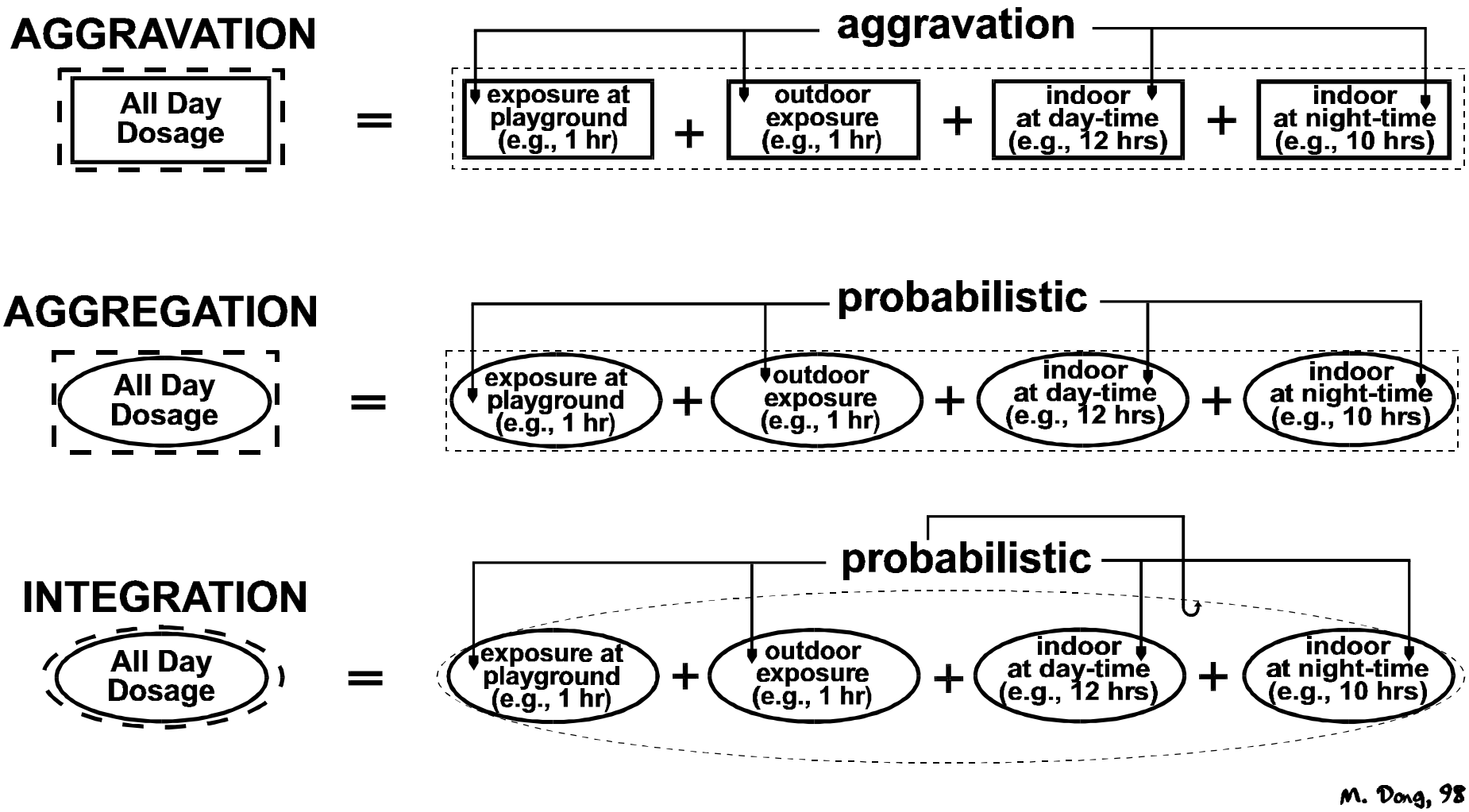
= {(indoor air level) x (hourly inhalation rate) x (duration) x (inhalation absorption) + (food residues) x (daily dietary consumption rate) x (oral absorption) + (water concentration) x (daily water consumption rate) x (oral absorption)}/(body weight).

IV. Indoor (night-time):

Dosage = inhalation [indoor air in a non-smoking area].

= {(indoor air level) x (hourly inhalation rate) x (duration) x (inhalation absorption)}/(body weight).

Fig 3. Various Approaches to Exposure Assessment



PARAMETERS/ASSUMPTIONS

In this case study, because an effort was made not to disclose the identity of the active ingredient, the various environmental (i.e., ambient air, water, soil, treated structure surface, etc.) concentrations were purposely either exaggerated or reduced by roughly 1.5 to 3.0 times of what had been found in the open literature or the registration documents. Yet in order to work with as real a case study as possible, the values used for many of the non-chemical specific parameters were either the usual defaults adopted by regulatory agencies including this Department (Thongsinthusak *et al*., 1993), or derived directly from U.S. EPA's *Exposure Factors Handbook* (1996). The values used in this paper for a couple non-chemical specific parameters, such as the time which a six-year-old child would spend at a playground in a given day, were based on intellectual or reasonable guessing, as such data were not readily available. The exposure-related parameters used, along with their values and their (in some cases, assumed) probability distributions (where applicable), are listed in the Appendix included in the handout.

As can be seen in the Appendix, a few parameters (e.g., dermal transfer factor, time duration, clothing penetration, etc.) were assigned a fixed value when in fact they could be treated as a random variable. Treating these few parameters as a constant reduced the complexity of the overall exposure assessment model undertaken. But more importantly, they were so treated mainly because at this time a realistic probabilistic distribution could not be determined or assumed for them.

RESULTS

(Absorbed Daily Dosage in μg/kg, by Activity)

Method	Playground	Outdoor	Indoor (day)	Indoor (nite)	All Day
					AGGRAVATION
Aggravation[a]	**27.06**	**2.29×10^{-3}**	**19.48**	**1.97×10^{-3}**	**46.54**
					AGGREGATION
Probabilistic[b]	**18.50**	**2.24×10^{-3}**	**7.17**	**1.99×10^{-3}**	**25.68**
					INTEGRATION
Probabilistic[c]	**(0.16)**	**(0.34×10^{-3})**	**(0.17)**	**(0.38×10^{-3})**	**20.13**

[a] synonymous with the conventional approach to calculating a point estimate for a worst case scenario; in this case study, a value around the 95th percentile was used for many of the exposure parameters involved, especially of those having a lognormal distribution (*see* Appendix in the handout for parameters, defaults, and distributions used).

[b] synonymous with Monte Carlo or the stochastic analysis; the dosages simulated above for the various outdoor and indoor activities were the 95th percentiles averaged over 10 simulation trials which each consisted of 10,000 runs (*see* Dong *et al*., 1994a, 1994b, for a general description of this technique and the definitions involved.) *Crystal Ball* (1996) was the computer software used to implement the Monte Carlo simulations.

[c] the values presented in parentheses above for the various outdoor and indoor activities were the 5th percentiles averaged over the 10 simulation trials; these 5th percentiles and the average 95th percentiles listed above under AGGREGATION, together with the average 100th percentiles as the upper range limit (and the assumption of a lognormal distribution), were used to run the final 10 Monte Carlo simulation trials that yielded a 95th percentile average for the all day exposure under INTEGRATION.

CONCULSIONS/OBSERVATIONS

1. **For the night-time indoor and non-playground outdoor exposure scenarios, the 95th percentile dosage simulated from the probabilistic analysis was very close to the point estimate calculated for a worst case scenario. This supports the expectation that for an exposure scenario involving one or two random variables, the use of probabilistic analysis normally is not warranted.**

2. **As expected, the night-time indoor and the non-playground outdoor exposures were negligible compared to that received either at playground or indoors at daytime.**

3. **The all day dosage calculated under AGGREGATION was about 55% of that calculated under AGGRAVATION (i.e., 25.7 *vs*. 46.5 μg/kg/day). And the all day dosage simulated under INTEGRATION was about 78% of that calculated under AGGREGATION (i.e., 20.1 *vs*. 25.7 μg/kg/day). (These differences in all day dosage might vary considerably if very different exposure scenarios were involved.)**

4. **The sensitivity analysis indicated that both the playground and the daytime indoor activities were most influential. And the most influential exposure parameter was the dislodgeable residues present on treated structure surfaces.**

5. **Insofar as the various hypothetical environmental concentrations were not too far from reality, this case study readily illustrated the potential that the background dose (i.e., from outdoor non-playground and indoor exposures) could easily be doubled for a six-year-old child spending just one hour at a site where playground structures were treated.**

6. **Because in this case study each simulation trial consisted of a large number of random samplings (i.e., 10,000 runs), no noticeable difference was found in the simulation results between using the conventional Monte Carlo sampling and the more accurate Latin Hypercube sampling method (for generation of random numbers).**

REFERENCES

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DISCLAIMER

No official endorsement of particular computer software by the California Department of Pesticide Regulation is intended or implied; the opinions expressed are those of the author and not necessarily those of the Department or of any other California state agency.

Appendix

Parameter (Reference)	Mean; Range	distribution	Playground	Outdoor	Indoor (Day)	Indoor (Nite)	All Day
outdoor ambient air (ηg/m^3) **(1)**	35 (30); 0 - 120 (0 - 100)	lognormal	***85.00***	***65.00***			
indoor/smoking (ηg/m^3) **(1)**	17; 0 - 100	lognormal			***50.00***		
indoor/nonsmoking (ηg/m^3) **(1)**	7.5; 0 - 50	lognormal				***15.00***	
inhalation rate (m^3/hr) **(2)**			0.78	0.78	0.78	0.29	
time duration for indoor/outdoor (hr) **(3)**			1.00	1.00	12.00	10.00	
inhalation absorption (%) **(2)**			1.00	1.00	1.00	1.00	
soil concentration (ppm) **(1)**	33; 0 - 150	lognormal	***120.00***	*(see* Fig 2)			
soil ingestion rate (mg/hr) **(4)**	30; 0 - 150	lognormal	***100.00***				
skin-soil loading (mg/cm^2) **(4)**	1.0; 0.5 - 1.5	uniform	1.50				
surface residues (μg/cm^2) **(1)**	0.5; 0 - 5	lognormal	***3.00***				
dermal transfer (μg/h per μg/cm^2) **(5)**	16,000		16,000.00				
dermal absorption (%) **(1)**	5		0.05				
% hand surface of total body **(4)**	5		0.05				
% hand surface residues for oral **(1)**	25		0.25				
oral absorption (%) **(2)**	100		1.00		1.00		
% body surface for skin-soil loading **(4)**	55		0.55				
time duration at playground (hr) **(3)**	0.5 - 3.0; half at soil area		1.00				
dietary (μg/day) [pre-calculated] **(1)**	10; 0 - 60	lognormal			***40.00***		
water concentration (μg/L) **(1)**	45; 0 - 500	lognormal			***300.00***		
water consumption (L/day) **(2)**	0.7; 0.0 - 1.5	normal			***1.30***		
body weight, BW (kg) **(2)**	22.1 ± 4.0; 17.0 - 29.6	normal	22.10	22.10	22.10	22.10	
body surface, SF (m^2) **(4)**	SF=(4xBW+7)/(BW+90)		0.85				
clothing penetration (%) **(2)**	10; 100 for uncovered		0.10				
% SF assumed to be clothed **(6)**	85		0.85				
			(The above italicized values in bold are presumably at the 95th - %tile.)				
Absorbed Daily Dosage (ηg/kg/day)							
point estimate (worst-case)			27,057.28	2.29	19,478.19	1.97	46,539.73

(1) hypothetical/presumed; **(2)** see Thongsinthusak *et al*., 1993/U.S. EPA's *Exposure Factors Handbook*, 1996; **(3)** reasonable guessing; **(4)** *see* Dong *et al*., 1994 1994b; **(5)** potential (prior to clothing protection), as for grape girdling or Jazzercise® type aggressive activity; **(6)** assuming 85% of body surface clothed.

Crystal Ball Report

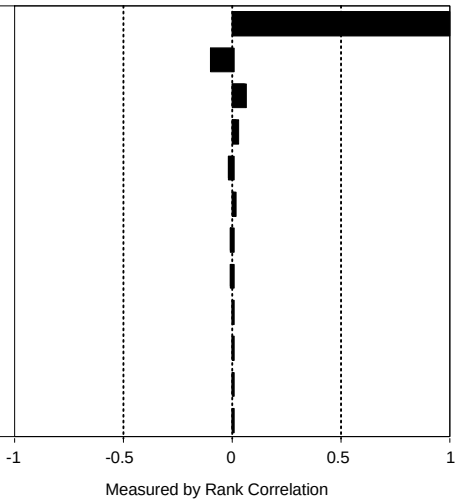
Simulation started on 2/18/98 at 14:06:29

Simulation stopped on 2/18/98 at 14:09:04

Sensitivity Chart

Target Forecast: Exposure at Playground

Dislodgeables on Structure (ug/cm2)	.99
Body Weight (kg) for 6-year-old	-.10
Soil Concentration (ppm)	.06
Skin-Soil Loading (mg/cm2), per event	.02
Indoor Air at Nitetime (ng/m3)	-.02
Soil Ingestion Rate (mg/hour)	.01
Ambient Air (ng/m3) around Playgrou...	-.01
Indoor Air at Daytime (ng/m3)	-.01
Water Consumption Rate (L/day)	.01
Dietary (ug/day)	.01
Ambient Air (ng/m3) - nonplayground	-.00
Water Concentration (ug/L)	-.00

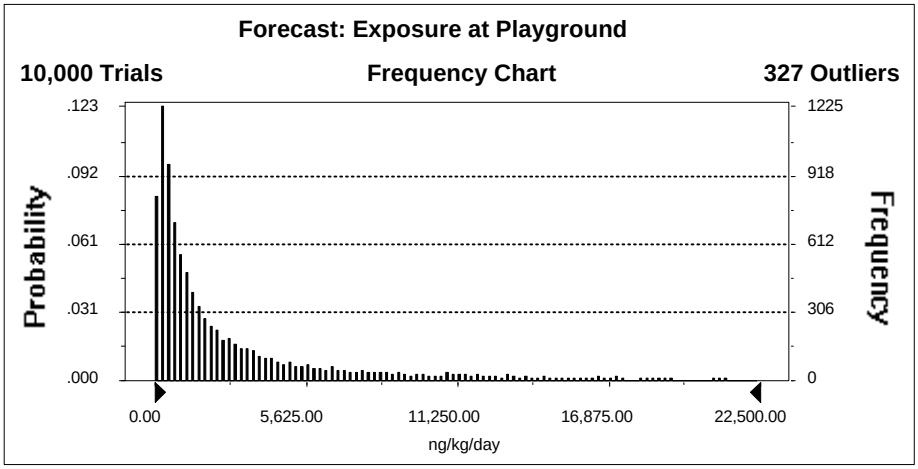


Forecast: Exposure at Playground **Cell: D32**

Summary:

Display Range is from 0.00 to 22,500.00 ng/kg/day
Entire Range is from 11.00 to 54,093.33 ng/kg/day
After 10,000 Trials, the Std. Error of the Mean is 66.85

Statistics:	Value
Trials	10000
Mean	4,096.29
Median	1,460.75
Mode	---
Standard Deviation	6,685.49
Variance	44,695,820.34
Skewness	3.14
Kurtosis	14.70
Coeff. of Variability	1.63
Range Minimum	11.00
Range Maximum	54,093.33
Range Width	54,082.33
Mean Std. Error	66.85



Forecast: Exposure at Playground (cont'd) **Cell: D32**

Percentiles:

Percentile	ng/kg/day
0%	11.00
5%	168.27
10%	259.25
15%	342.11
20%	437.58
25%	548.66
30%	667.36
35%	824.50
40%	997.91
45%	1,208.74
50%	1,460.75
55%	1,767.46
60%	2,196.70
65%	2,734.43
70%	3,409.31
75%	4,326.53
80%	5,714.71
85%	7,870.88
90%	11,304.15
95%	17,540.83
100%	54,093.33

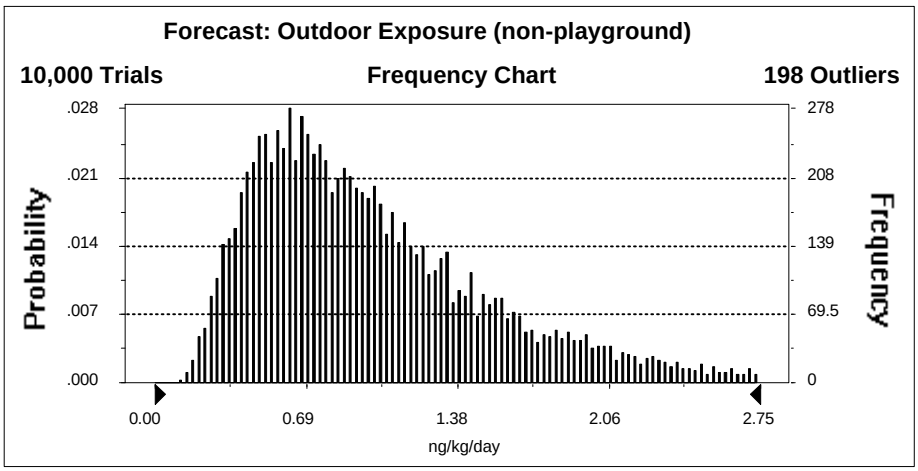
End of Forecast

Forecast: Outdoor Exposure (non-playground) **Cell: E32**

Summary:

Display Range is from 0.00 to 2.75 ng/kg/day
Entire Range is from 0.10 to 4.15 ng/kg/day
After 10,000 Trials, the Std. Error of the Mean is 0.01

Statistics:	Value
Trials	10000
Mean	1.03
Median	0.88
Mode	---
Standard Deviation	0.61
Variance	0.37
Skewness	1.39
Kurtosis	5.35
Coeff. of Variability	0.59
Range Minimum	0.10
Range Maximum	4.15
Range Width	4.05
Mean Std. Error	0.01



Forecast: Outdoor Exposure (non-playground) (cont'd) **Cell: E32**

Percentiles:

Percentile	ng/kg/day
0%	0.10
5%	0.33
10%	0.42
15%	0.48
20%	0.53
25%	0.59
30%	0.64
35%	0.70
40%	0.75
45%	0.82
50%	0.88
55%	0.95
60%	1.02
65%	1.10
70%	1.20
75%	1.31
80%	1.44
85%	1.60
90%	1.86
95%	2.24
100%	4.15

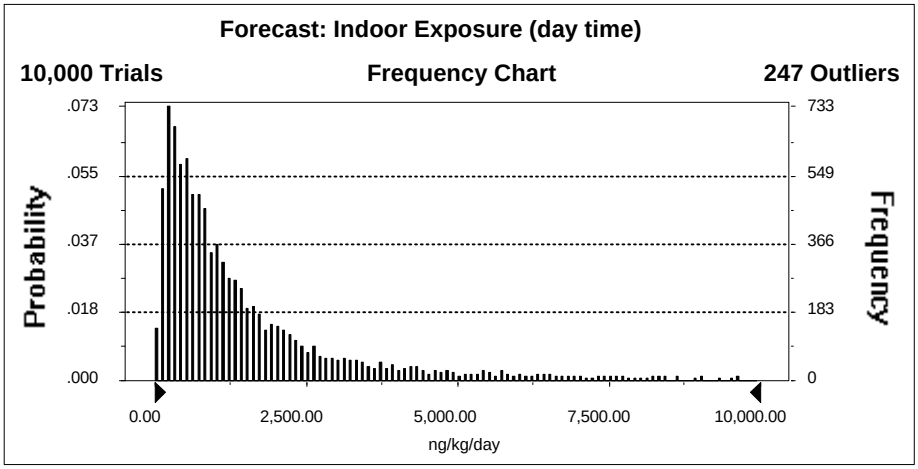
End of Forecast

Forecast: Indoor Exposure (day time) **Cell: F32**

Summary:

Display Range is from 0.00 to 10,000.00 ng/kg/day
Entire Range is from 20.15 to 30,583.54 ng/kg/day
After 10,000 Trials, the Std. Error of the Mean is 27.37

Statistics:	Value
Trials	10000
Mean	1,898.14
Median	980.59
Mode	---
Standard Deviation	2,737.03
Variance	7,491,314.26
Skewness	3.77
Kurtosis	22.40
Coeff. of Variability	1.44
Range Minimum	20.15
Range Maximum	30,583.54
Range Width	30,563.39
Mean Std. Error	27.37



Forecast: Indoor Exposure (day time) (cont'd) **Cell: F32**

Percentiles:

Percentile	ng/kg/day
0%	20.15
5%	174.02
10%	249.01
15%	314.69
20%	388.92
25%	473.80
30%	553.91
35%	648.46
40%	750.26
45%	850.96
50%	980.59
55%	1,127.57
60%	1,295.94
65%	1,490.16
70%	1,745.17
75%	2,070.99
80%	2,484.94
85%	3,222.56
90%	4,419.99
95%	7,030.99
100%	30,583.54

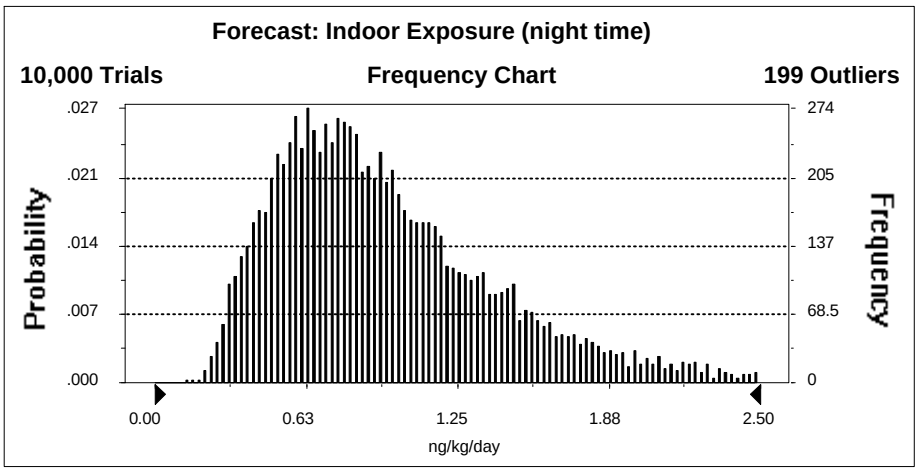
End of Forecast

Forecast: Indoor Exposure (night time) **Cell: G32**

Summary:

Display Range is from 0.00 to 2.50 ng/kg/day
Entire Range is from 0.13 to 5.81 ng/kg/day
After 10,000 Trials, the Std. Error of the Mean is 0.01

Statistics:	Value
Trials	10000
Mean	0.99
Median	0.87
Mode	---
Standard Deviation	0.53
Variance	0.28
Skewness	1.68
Kurtosis	7.89
Coeff. of Variability	0.53
Range Minimum	0.13
Range Maximum	5.81
Range Width	5.68
Mean Std. Error	0.01



Forecast: Indoor Exposure (night time) (cont'd) **Cell: G32**

Percentiles:

Percentile	ng/kg/day
0%	0.13
5%	0.38
10%	0.46
15%	0.52
20%	0.57
25%	0.62
30%	0.67
35%	0.72
40%	0.77
45%	0.82
50%	0.87
55%	0.93
60%	0.99
65%	1.06
70%	1.14
75%	1.23
80%	1.34
85%	1.47
90%	1.66
95%	1.99
100%	5.81

End of Forecast

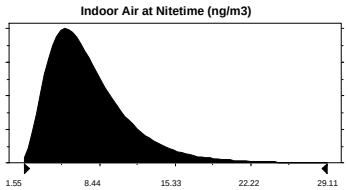
Assumptions

Assumption: Indoor Air at Nitetime (ng/m3) **Cell: G5**

Lognormal distribution with parameters:

5% - tile	3.00
95% - tile	15.00

Selected range is from 0.00 to 50.00
Mean value in simulation was 7.59

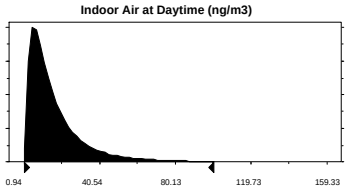


Assumption: Indoor Air at Daytime (ng/m3) **Cell: F4**

Lognormal distribution with parameters:

5% - tile	3.00
95% - tile	50.00

Selected range is from 0.00 to 100.00
Mean value in simulation was 16.63

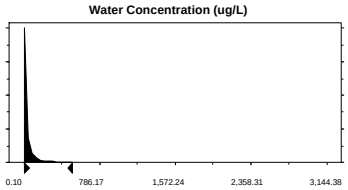


Assumption: Water Concentration (ug/L) **Cell: F23**

Lognormal distribution with parameters:

5% - tile	1.00
95% - tile	300.00

Selected range is from 0.00 to 500.00
Mean value in simulation was 45.30

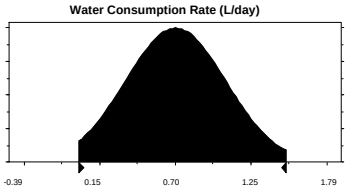


Assumption: Water Consumption Rate (L/day) **Cell: F24**

Normal distribution with parameters:

Mean	0.70
95% - tile	1.30

Selected range is from 0.00 to 1.50
Mean value in simulation was 0.71

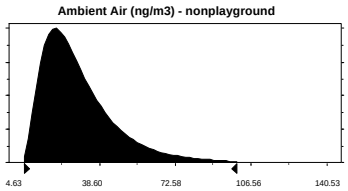


Assumption: Ambient Air (ng/m3) - nonplayground **Cell: E3**

Lognormal distribution with parameters:

5% - tile	10.00
95% - tile	65.00

Selected range is from 0.00 to 100.00
Mean value in simulation was 29.21

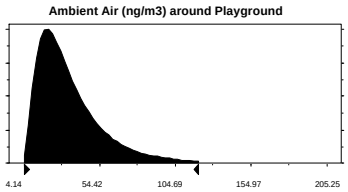


Assumption: Ambient Air (ng/m3) around Playground **Cell: D3**

Lognormal distribution with parameters:

5% - tile	10.00
95% - tile	85.00

Selected range is from 0.00 to 120.00
Mean value in simulation was 34.09

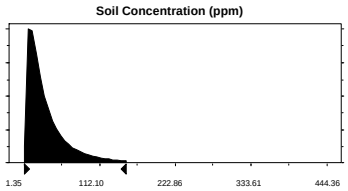


Assumption: Soil Concentration (ppm) **Cell: D10**

Lognormal distribution with parameters:

5% - tile	5.00
95% - tile	120.00

Selected range is from 0.00 to 150.00
Mean value in simulation was 32.85

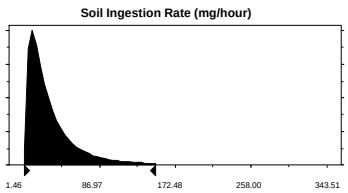


Assumption: Soil Ingestion Rate (mg/hour) **Cell: D11**

Lognormal distribution with parameters:

5% - tile	5.00
95% - tile	100.00

Selected range is from 0.00 to 150.00
Mean value in simulation was 30.24

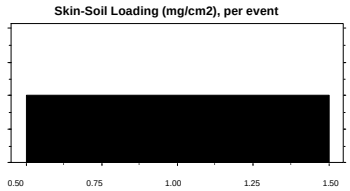


Assumption: Skin-Soil Loading (mg/cm2), per event **Cell: D12**

Uniform distribution with parameters:

Minimum	0.50
Maximum	1.50

Mean value in simulation was 1.00

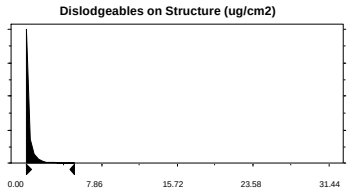


Assumption: Dislodgeables on Structure (ug/cm2) **Cell: D13**

Lognormal distribution with parameters:

5% - tile	0.01
95% - tile	3.00

Selected range is from 0.00 to 5.00
Mean value in simulation was 0.45

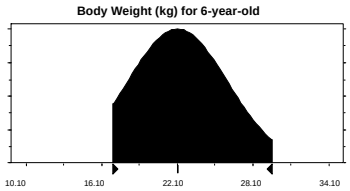


Assumption: Body Weight (kg) for 6-year-old **Cell: D26**

Normal distribution with parameters:

Mean	22.10
Standard Dev.	4.00

Selected range is from 17.00 to 29.60
Mean value in simulation was 22.58

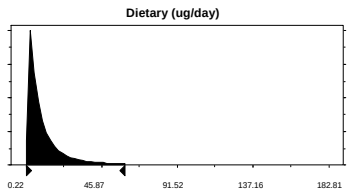


Assumption: Dietary (ug/day) **Cell: F21**

Lognormal distribution with parameters:

5% - tile	1.00
95% - tile	40.00

Selected range is from 0.00 to 60.00
Mean value in simulation was 9.84



End of Assumptions