SBML Model Report

Model name: “Wodarz2007 - Cytomegalovirus infection model with cytotoxic T lymphocyte and natural killer cell response”

May 17, 2018

1 General Overview

This is a document in SBML Level 2 Version 4 format. This model was created by the following two authors: Catherine Lloyd[1] and Matthew Grant Roberts[2] at June 25th 2010 at 1:17 p. m. and last time modified at March twelveth 2018 at 10:38 a. m. Table 1 provides an overview of the quantities of all components of this model.

Table 1: Number of components in this model, which are described in the following sections.

Element	Quantity	Element	Quantity
compartment types	0	compartments	1
species types	0	species	16
events	0	constraints	0
reactions	30	function definitions	6
global parameters	20	unit definitions	1
rules	1	initial assignments	0

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Model Notes

This a model from the article:
Dynamics of killer T cell inflation in viral infections.
Wodarz D, Sierro S, Klenerman P. J R Soc Interface 2007 Jun 22;4(14):533-43 17251133 ,
Abstract:
Upon acute viral infection, a typical cytotoxic T lymphocyte (CTL) response ischaracterized by a phase of expansion and contraction after which it settles ata relatively stable memory level. Recently, experimental data from mice infectedwith murine cytomegalovirus (MCMV) showed different and unusual dynamics. Afteracute infection had resolved, some antigen specific CTL started to expand overtime despite the fact that no replicative virus was detectable. This phenomenonhas been termed as „CTL memory inflation„. In order to examine the dynamics ofthis system further, we developed a mathematical model analysing the impact ofinnate and adaptive immune responses. According to this model, a potentiallyimportant contributor to CTL inflation is competition between the specific CTLresponse and an innate natural killer (NK) cell response. Inflation occurs mostreadily if the NK cell response is more efficient than the CTL at reducing virusload during acute infection, but thereafter maintains a chronic virus load whichis sufficient to induce CTL proliferation. The model further suggests thatweaker NK cell mediated protection can correlate with more pronounced CTLinflation dynamics over time. We present experimental data from mice infectedwith MCMV which are consistent with the theoretical predictions. This modelprovides valuable information and may help to explain the inflation of CMVspecific CD8+T cells seen in humans as they age.

This model was taken from the CellML repository and automatically converted to SBML.
The original model was: **Wodarz D, Sierro S, Klenerman P. (2007) - version=1.0**
The original CellML model was created by:
Catherine Lloyd
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The University of Auckland

2 Unit Definitions

This is an overview of five unit definitions of which four are predefined by SBML and not mentioned in the model.

2.1 Unit `time`

Name time

Definition 3600 s

2.2 Unit `substance`

Notes Mole is the predefined SBML unit for `substance`.

Definition mol

2.3 Unit `volume`

Notes Litre is the predefined SBML unit for `volume`.

Definition l

2.4 Unit `area`

Notes Square metre is the predefined SBML unit for `area` since SBML Level 2 Version 1.

Definition m^2

2.5 Unit `length`

Notes Metre is the predefined SBML unit for `length` since SBML Level 2 Version 1.

Definition m

3 Compartment

This model contains one compartment.

Table 2: Properties of all compartments.

Id	Name	SBO	Spatial Dimensions	Size	Unit	Constant	Outside
`COMpartment`	Mouse		3	1	litre	☑	

3.1 Compartment `COMpartment`

This is a three dimensional compartment with a constant size of one litre.

Name Mouse

4 Species

This model contains 16 species. Section 9 provides further details and the derived rates of change of each species.

Table 3: Properties of each species.

Id	Name	Compartment	Derived Unit	Constant	Boundary Condition
x	x	COMpartment	$\mathrm{mol} \cdot \mathrm{l}^{-1}$	⊟	⊟
y_0	y_0	COMpartment	$\mathrm{mol} \cdot \mathrm{l}^{-1}$	⊟	⊟
y_1	y_1	COMpartment	$\mathrm{mol} \cdot \mathrm{l}^{-1}$	⊟	⊟
L	L	COMpartment	$\mathrm{mol} \cdot \mathrm{l}^{-1}$	⊟	⊟
v	v	COMpartment	$\mathrm{mol} \cdot \mathrm{l}^{-1}$	⊟	⊟
z_a	z_a	COMpartment	$\mathrm{mol} \cdot \mathrm{l}^{-1}$	⊟	⊟
m_0	m_0	COMpartment	$\mathrm{mol} \cdot \mathrm{l}^{-1}$	⊟	⊟
m_1	m_1	COMpartment	$\mathrm{mol} \cdot \mathrm{l}^{-1}$	⊟	⊟
m_2	m_2	COMpartment	$\mathrm{mol} \cdot \mathrm{l}^{-1}$	⊟	⊟
m_3	m_3	COMpartment	$\mathrm{mol} \cdot \mathrm{l}^{-1}$	⊟	⊟
m_4	m_4	COMpartment	$\mathrm{mol} \cdot \mathrm{l}^{-1}$	⊟	⊟
m_5	m_5	COMpartment	$\mathrm{mol} \cdot \mathrm{l}^{-1}$	⊟	⊟
m_6	m_6	COMpartment	$\mathrm{mol} \cdot \mathrm{l}^{-1}$	⊟	⊟
m_7	m_7	COMpartment	$\mathrm{mol} \cdot \mathrm{l}^{-1}$	⊟	⊟
m_8	m_8	COMpartment	$\mathrm{mol} \cdot \mathrm{l}^{-1}$	⊟	⊟
z_i	z_i	COMpartment	$\mathrm{mol} \cdot \mathrm{l}^{-1}$	⊟	⊟

5 Parameters

This model contains 20 global parameters.

Table 4: Properties of each parameter.

Id	Name	SBO	Value	Unit	Constant
R0	R0		15.909		☐
a0	a0		0.100		☑
a1	a1		0.200		☑
k	k		1.000		☑
u	u		1.000		☑
lambda	lambda		10.000		☑
d	d		0.100		☑
beta	beta		0.100		☑
gamma	gamma		0.500		☑
alpha	alpha		0.200		☑
phi	phi		0.100		☑
eta	eta		0.010		☑
pa	pa		10^{-6}		☑
ca	ca		15.500		☑
r	r		1.000		☑
ba	ba		0.100		☑
p_i	p_i		1.000		☑
ci	ci		12.000		☑
bi	bi		0.100		☑
xi	xi		0.010		☑

6 Function definitions

This is an overview of six function definitions.

6.1 Function definition Constant_flux__irreversible

Name Constant flux (irreversible)

Argument [v]

Mathematical Expression

$$[\mathrm{v}] \tag{1}$$

6.2 Function definition `function`

Name function

Arguments parameter, modifier, substrate

Mathematical Expression

$$\text{parameter} \cdot \text{modifier} \cdot \text{substrate} \tag{2}$$

6.3 Function definition `function_1`

Name function_1

Arguments param, mod

Mathematical Expression

$$\text{param} \cdot \text{mod} \tag{3}$$

6.4 Function definition `function_2`

Name function_2

Arguments parameter, modifier

Mathematical Expression

$$\text{parameter} \cdot \text{modifier} \tag{4}$$

6.5 Function definition `function_3`

Name function_3

Arguments c_a, y0, y1, za

Mathematical Expression

$$\text{c\_a} \cdot (\text{y0} + \text{y1}) \cdot \text{za} \tag{5}$$

6.6 Function definition `function_4`

Name function_4

Arguments c_i, y0, y1, zi

Mathematical Expression

$$\text{c\_i} \cdot (\text{y0} + \text{y1}) \cdot \text{zi} \tag{6}$$

7 Rule

This is an overview of one rule.

7.1 Rule R0

Rule R0 is an assignment rule for parameter R0:

$$\mathrm{R0} = \frac{\mathrm{lambda} \cdot \mathrm{eta}}{\mathrm{d} \cdot \mathrm{a1} \cdot (\mathrm{a0} + \mathrm{eta})} \cdot \left(\mathrm{beta} + \frac{\mathrm{gamma} \cdot \mathrm{phi}}{\mathrm{phi} + \mathrm{d}} \right) \tag{7}$$

8 Reactions

This model contains 30 reactions. All reactions are listed in the following table and are subsequently described in detail. If a reaction is affected by a modifier, the identifier of this species is written above the reaction arrow.

Table 5: Overview of all reactions

№	Id	Name	Reaction Equation	SBO
1	Host_cell_proliferation	Host cell proliferation	$\emptyset \longrightarrow x$	
2	Host_cell_death	Host cell death	$x \longrightarrow \emptyset$	
3	Infection_1	Infection 1	$x \xrightarrow{v} y\_0$	
4	Infection_2	Infection 2	$x \xrightarrow{v} L$	
5	Infected_cell_death_1	Infected cell death 1	$y\_0 \longrightarrow \emptyset$	
6	Infected_cell_infection_progression_1	Infected cell infection progression 1	$y\_0 \longrightarrow y\_1$	
7	Infected_cell_infection_progression_2	Infected cell infection progression 2	$L \longrightarrow y\_0$	
8	CTL_induced_infected_cell_death_1	CTL-induced infected cell death 1	$y\_0 \xrightarrow{z\_a} \emptyset$	
9	Infected_cell_death_2	Infected cell death 2	$y\_1 \longrightarrow \emptyset$	
10	CTL_induced_infected_cell_death_2	CTL-induced infected cell death 2	$y\_1 \xrightarrow{z\_a} \emptyset$	

№	Id	Name	Reaction Equation	SBO
11	Infected_cell_death_3	Infected cell death 3	$L \longrightarrow \emptyset$	
12	Virus_particle_production	Virus particle production	$\emptyset \xrightarrow{y\_1} v$	
13	Viral_particle_degradation	Viral particle degradation	$v \longrightarrow \emptyset$	
14	Precursor_T_cell_differentiation_2	Precursor T-cell differentiation 2	$\emptyset \xrightarrow{m\_8} z\_a$	
15	Infection_induced_CTL_proliferation_stimulation	Infection-induced CTL proliferation stimulation	$\emptyset \xrightarrow{y\_0,\ y\_1} z\_a$	
16	CTL_cell_death	CTL cell death	$z\_a \longrightarrow \emptyset$	
17	Naive_CTL_division_1	Naive CTL division 1	$m\_0 \longrightarrow 2\, m\_1$	
18	Naive_CTL_division_2	Naive CTL division 2	$m\_1 \longrightarrow 2\, m\_2$	
19	Naive_CTL_division_3	Naive CTL division 3	$m\_2 \longrightarrow 2\, m\_3$	
20	Naive_CTL_division_4	Naive CTL division 4	$m\_3 \longrightarrow 2\, m\_4$	
21	Naive_CTL_division_5	Naive CTL division 5	$m\_4 \longrightarrow 2\, m\_5$	
22	Naive_CTL_division_6	Naive CTL division 6	$m\_5 \longrightarrow 2\, m\_6$	

№	Id	Name	Reaction Equation	SBO
23	Naive_CTL-_division_7	Naive CTL division 7	$m\_6 \longrightarrow 2\, m\_7$	
24	Naive_CTL-_division_8	Naive CTL division 8	$m\_7 \longrightarrow 2\, m\_8$	
25	Precursor-_T_cell-_differentiation-_1	Precursor T-cell differentiation 1	$m\_8 \longrightarrow \emptyset$	
26	NK_cell-_production	NK cell production	$\emptyset \longrightarrow z\_i$	
27	NK_infection-_induced-_production	NK infection-induced production	$\emptyset \xrightarrow{y\_0,\ y\_1} z\_i$	
28	NK_cell_death	NK cell death	$z\_i \longrightarrow \emptyset$	
29	NK_induced-_infected_cell-_death_1	NK-induced infected cell death 1	$y\_0 \xrightarrow{z\_i} \emptyset$	
30	NK_induced-_infected_cell-_death_2	NK-induced infected cell death 2	$y\_1 \xrightarrow{z\_i} \emptyset$	

8.1 Reaction Host_cell_proliferation

This is an irreversible reaction of no reactant forming one product.

Name Host cell proliferation

Reaction equation

$$\emptyset \longrightarrow \mathrm{x} \tag{8}$$

Product

Table 6: Properties of each product.

Id	Name	SBO
x	x	

Kinetic Law

Derived unit contains undeclared units

$$v_1 = \mathrm{vol}\left(\mathrm{COMpartment}\right) \cdot \mathrm{Constant\_flux\_\_irreversible}\left(\mathrm{lambda}\right) \tag{9}$$

$$\mathrm{Constant\_flux\_\_irreversible}\left([\mathrm{v}]\right) = [\mathrm{v}] \tag{10}$$

$$\mathrm{Constant\_flux\_\_irreversible}\left([\mathrm{v}]\right) = [\mathrm{v}] \tag{11}$$

8.2 Reaction Host_cell_death

This is an irreversible reaction of one reactant forming no product.

Name Host cell death

Reaction equation

$$\mathrm{x} \longrightarrow \emptyset \tag{12}$$

Reactant

Table 7: Properties of each reactant.

Id	Name	SBO
x	x	

Kinetic Law

Derived unit contains undeclared units

$$v_2 = \mathrm{vol}\,(\mathrm{COMpartment}) \cdot \mathrm{d} \cdot [\mathrm{x}] \tag{13}$$

8.3 Reaction `Infection_1`

This is an irreversible reaction of one reactant forming one product influenced by one modifier.

Name Infection 1

Reaction equation

$$\mathrm{x} \xrightarrow{\mathrm{v}} \mathrm{y\_0} \tag{14}$$

Reactant

Table 8: Properties of each reactant.

Id	Name	SBO
x	x	

Modifier

Table 9: Properties of each modifier.

Id	Name	SBO
v	v	

Product

Table 10: Properties of each product.

Id	Name	SBO
y_0	y_0	

Kinetic Law

Derived unit contains undeclared units

$$v_3 = \text{vol}\left(\text{COMpartment}\right) \cdot \text{function}\left(\text{beta}, [\text{v}], [\text{x}]\right) \tag{15}$$

$$\text{function}\left(\text{parameter}, \text{modifier}, \text{substrate}\right) = \text{parameter} \cdot \text{modifier} \cdot \text{substrate} \tag{16}$$

$$\text{function}\left(\text{parameter}, \text{modifier}, \text{substrate}\right) = \text{parameter} \cdot \text{modifier} \cdot \text{substrate} \tag{17}$$

8.4 Reaction `Infection_2`

This is an irreversible reaction of one reactant forming one product influenced by one modifier.

Name Infection 2

Reaction equation

$$\text{x} \xrightarrow{\text{v}} \text{L} \tag{18}$$

Reactant

Table 11: Properties of each reactant.

Id	Name	SBO
x	x	

Modifier

Table 12: Properties of each modifier.

Id	Name	SBO
v	v	

Product

Table 13: Properties of each product.

Id	Name	SBO
L	L	

Kinetic Law

Derived unit contains undeclared units

$$v_4 = \mathrm{vol}\,(\mathrm{COMpartment}) \cdot \mathrm{function}\,(\mathrm{gamma}, [\mathrm{v}], [\mathrm{x}]) \tag{19}$$

$$\mathrm{function}\,(\mathrm{parameter}, \mathrm{modifier}, \mathrm{substrate}) = \mathrm{parameter} \cdot \mathrm{modifier} \cdot \mathrm{substrate} \tag{20}$$

$$\mathrm{function}\,(\mathrm{parameter}, \mathrm{modifier}, \mathrm{substrate}) = \mathrm{parameter} \cdot \mathrm{modifier} \cdot \mathrm{substrate} \tag{21}$$

8.5 Reaction `Infected_cell_death_1`

This is an irreversible reaction of one reactant forming no product.

Name Infected cell death 1

Reaction equation

$$\mathrm{y\_0} \longrightarrow \emptyset \tag{22}$$

Reactant

Table 14: Properties of each reactant.

Id	Name	SBO
y_0	y_0	

Kinetic Law

Derived unit contains undeclared units

$$v_5 = \mathrm{vol}\,(\mathrm{COMpartment}) \cdot \mathrm{a0} \cdot [\mathrm{y\_0}] \tag{23}$$

8.6 Reaction Infected_cell_infection_progression_1

This is an irreversible reaction of one reactant forming one product.

Name Infected cell infection progression 1

Reaction equation

$$\mathrm{y\_0} \longrightarrow \mathrm{y\_1} \tag{24}$$

Reactant

Table 15: Properties of each reactant.

Id	Name	SBO
y_0	y_0	

Product

Table 16: Properties of each product.

Id	Name	SBO
y_1	y_1	

Kinetic Law

Derived unit contains undeclared units

$$v_6 = \mathrm{vol}\left(\mathrm{COMpartment}\right) \cdot \mathrm{eta} \cdot [\mathrm{y\_0}] \tag{25}$$

8.7 Reaction Infected_cell_infection_progression_2

This is an irreversible reaction of one reactant forming one product.

Name Infected cell infection progression 2

Reaction equation

$$\mathrm{L} \longrightarrow \mathrm{y\_0} \tag{26}$$

Reactant

Table 17: Properties of each reactant.

Id	Name	SBO
L	L	

Product

Table 18: Properties of each product.

Id	Name	SBO
y_0	y_0	

Kinetic Law

Derived unit contains undeclared units

$$v_7 = \mathrm{vol}\left(\mathrm{COMpartment}\right) \cdot \mathrm{phi} \cdot [\mathrm{L}] \tag{27}$$

8.8 Reaction CTL_induced_infected_cell_death_1

This is an irreversible reaction of one reactant forming no product influenced by one modifier.

Name CTL-induced infected cell death 1

Reaction equation

$$\mathrm{y\_0} \xrightarrow{\mathrm{z\_a}} \emptyset \tag{28}$$

Reactant

Table 19: Properties of each reactant.

Id	Name	SBO
y_0	y_0	

Modifier

Table 20: Properties of each modifier.

Id	Name	SBO
z_a	z_a	

Kinetic Law

Derived unit contains undeclared units

$$v_8 = \mathrm{vol}\,(\mathrm{COMpartment}) \cdot \mathrm{function}\,(\mathrm{pa}, [\mathrm{z\_a}], [\mathrm{y\_0}]) \tag{29}$$

$$\mathrm{function}\,(\mathrm{parameter}, \mathrm{modifier}, \mathrm{substrate}) = \mathrm{parameter} \cdot \mathrm{modifier} \cdot \mathrm{substrate} \tag{30}$$

$$\mathrm{function}\,(\mathrm{parameter}, \mathrm{modifier}, \mathrm{substrate}) = \mathrm{parameter} \cdot \mathrm{modifier} \cdot \mathrm{substrate} \tag{31}$$

8.9 Reaction Infected_cell_death_2

This is an irreversible reaction of one reactant forming no product.

Name Infected cell death 2

Reaction equation

$$\mathrm{y\_1} \longrightarrow \emptyset \tag{32}$$

Reactant

Table 21: Properties of each reactant.

Id	Name	SBO
y_1	y_1	

Kinetic Law

Derived unit contains undeclared units

$$v_9 = \mathrm{vol}\,(\mathrm{COMpartment}) \cdot \mathrm{a1} \cdot [\mathrm{y\_1}] \tag{33}$$

8.10 Reaction CTL_induced_infected_cell_death_2

This is an irreversible reaction of one reactant forming no product influenced by one modifier.

Name CTL-induced infected cell death 2

Reaction equation

$$\mathrm{y\_1} \xrightarrow{\mathrm{z\_a}} \emptyset \tag{34}$$

Reactant

Table 22: Properties of each reactant.

Id	Name	SBO
y_1	y_1	

Modifier

Table 23: Properties of each modifier.

Id	Name	SBO
z_a	z_a	

Kinetic Law

Derived unit contains undeclared units

$$v_{10} = \mathrm{vol}\left(\mathrm{COMpartment}\right) \cdot \mathrm{function}\left(\mathrm{pa}, [\mathrm{z\_a}], [\mathrm{y\_1}]\right) \tag{35}$$

$$\mathrm{function}\left(\mathrm{parameter}, \mathrm{modifier}, \mathrm{substrate}\right) = \mathrm{parameter} \cdot \mathrm{modifier} \cdot \mathrm{substrate} \tag{36}$$

$$\mathrm{function}\left(\mathrm{parameter}, \mathrm{modifier}, \mathrm{substrate}\right) = \mathrm{parameter} \cdot \mathrm{modifier} \cdot \mathrm{substrate} \tag{37}$$

8.11 Reaction Infected_cell_death_3

This is an irreversible reaction of one reactant forming no product.

Name Infected cell death 3

Reaction equation

$$\mathrm{L} \longrightarrow \emptyset \tag{38}$$

Reactant

Table 24: Properties of each reactant.

Id	Name	SBO
L	L	

Kinetic Law

Derived unit contains undeclared units

$$v_{11} = \mathrm{vol}\left(\mathrm{COMpartment}\right) \cdot \mathrm{d} \cdot [\mathrm{L}] \tag{39}$$

8.12 Reaction Virus_particle_production

This is an irreversible reaction of no reactant forming one product influenced by one modifier.

Name Virus particle production

Reaction equation

$$\emptyset \xrightarrow{\mathrm{y\_1}} \mathrm{v} \tag{40}$$

Modifier

Table 25: Properties of each modifier.

Id	Name	SBO
y_1	y_1	

Product

Table 26: Properties of each product.

Id	Name	SBO
v	v	

Kinetic Law

Derived unit contains undeclared units

$$v_{12} = \mathrm{vol}\left(\mathrm{COMpartment}\right) \cdot \mathrm{function\_1}\left(\mathrm{k}, [\mathrm{y\_1}]\right) \tag{41}$$

$$\text{function\_1}\,(\text{param}, \text{mod}) = \text{param} \cdot \text{mod} \tag{42}$$

$$\text{function\_1}\,(\text{param}, \text{mod}) = \text{param} \cdot \text{mod} \tag{43}$$

8.13 Reaction Viral_particle_degradation

This is an irreversible reaction of one reactant forming no product.

Name Viral particle degradation

Reaction equation

$$\text{v} \longrightarrow \emptyset \tag{44}$$

Reactant

Table 27: Properties of each reactant.

Id	Name	SBO
v	v	

Kinetic Law

Derived unit contains undeclared units

$$v_{13} = \text{vol}\,(\text{COMpartment}) \cdot \text{u} \cdot [\text{v}] \tag{45}$$

8.14 Reaction Precursor_T_cell_differentiation_2

This is an irreversible reaction of no reactant forming one product influenced by one modifier.

Name Precursor T-cell differentiation 2

Reaction equation

$$\emptyset \xrightarrow{\text{m\_8}} \text{z\_a} \tag{46}$$

Modifier

Table 28: Properties of each modifier.

Id	Name	SBO
m_8	m_8	

Product

Table 29: Properties of each product.

Id	Name	SBO
z_a	z_a	

Kinetic Law

Derived unit contains undeclared units

$$v_{14} = \mathrm{vol}\left(\mathrm{COMpartment}\right) \cdot \mathrm{function\_2}\left(\mathrm{alpha}, [\mathrm{m\_8}]\right) \tag{47}$$

$$\mathrm{function\_2}\left(\mathrm{parameter}, \mathrm{modifier}\right) = \mathrm{parameter} \cdot \mathrm{modifier} \tag{48}$$

$$\mathrm{function\_2}\left(\mathrm{parameter}, \mathrm{modifier}\right) = \mathrm{parameter} \cdot \mathrm{modifier} \tag{49}$$

8.15 Reaction Infection_induced_CTL_proliferation_stimulation

This is an irreversible reaction of no reactant forming one product influenced by two modifiers.

Name Infection-induced CTL proliferation stimulation

Reaction equation

$$\emptyset \xrightarrow{\mathrm{y\_0},\ \mathrm{y\_1}} \mathrm{z\_a} \tag{50}$$

Modifiers

Table 30: Properties of each modifier.

Id	Name	SBO
y_0	y_0	
y_1	y_1	

Product

Table 31: Properties of each product.

Id	Name	SBO
z_a	z_a	

Kinetic Law

Derived unit contains undeclared units

$$v_{15} = \mathrm{vol}\,(\mathrm{COMpartment}) \cdot \mathrm{function\_3}\,(\mathrm{ca}, [\mathrm{y\_0}], [\mathrm{y\_1}], [\mathrm{z\_a}]) \tag{51}$$

$$\mathrm{function\_3}\,(\mathrm{c\_a}, \mathrm{y0}, \mathrm{y1}, \mathrm{za}) = \mathrm{c\_a} \cdot (\mathrm{y0} + \mathrm{y1}) \cdot \mathrm{za} \tag{52}$$

$$\mathrm{function\_3}\,(\mathrm{c\_a}, \mathrm{y0}, \mathrm{y1}, \mathrm{za}) = \mathrm{c\_a} \cdot (\mathrm{y0} + \mathrm{y1}) \cdot \mathrm{za} \tag{53}$$

8.16 Reaction CTL_cell_death

This is an irreversible reaction of one reactant forming no product.

Name CTL cell death

Reaction equation

$$\mathrm{z\_a} \longrightarrow \emptyset \tag{54}$$

Reactant

Table 32: Properties of each reactant.

Id	Name	SBO
z_a	z_a	

Kinetic Law

Derived unit contains undeclared units

$$v_{16} = \mathrm{vol}\,(\mathrm{COMpartment}) \cdot \mathrm{ba} \cdot [\mathrm{z\_a}] \tag{55}$$

8.17 Reaction Naive_CTL_division_1

This is an irreversible reaction of one reactant forming one product.

Name Naive CTL division 1

Reaction equation

$$\mathrm{m\_0} \longrightarrow 2\,\mathrm{m\_1} \tag{56}$$

Reactant

Table 33: Properties of each reactant.

Id	Name	SBO
m_0	m_0	

Product

Table 34: Properties of each product.

Id	Name	SBO
m_1	m_1	

Kinetic Law

Derived unit contains undeclared units

$$v_{17} = \mathrm{vol}\,(\mathrm{COMpartment}) \cdot \mathrm{r} \cdot [\mathrm{m\_0}] \tag{57}$$

8.18 Reaction Naive_CTL_division_2

This is an irreversible reaction of one reactant forming one product.

Name Naive CTL division 2

Reaction equation

$$\mathrm{m\_1} \longrightarrow 2\,\mathrm{m\_2} \tag{58}$$

Reactant

Table 35: Properties of each reactant.

Id	Name	SBO
m_1	m_1	

Product

Table 36: Properties of each product.

Id	Name	SBO
m_2	m_2	

Kinetic Law

Derived unit contains undeclared units

$$v_{18} = \mathrm{vol}\,(\mathrm{COMpartment}) \cdot \mathrm{r} \cdot [\mathrm{m\_1}] \tag{59}$$

8.19 Reaction Naive_CTL_division_3

This is an irreversible reaction of one reactant forming one product.

Name Naive CTL division 3

Reaction equation

$$\mathrm{m\_2} \longrightarrow 2\,\mathrm{m\_3} \tag{60}$$

Reactant

Table 37: Properties of each reactant.

Id	Name	SBO
m_2	m_2	

Product

Table 38: Properties of each product.

Id	Name	SBO
m_3	m_3	

Kinetic Law

Derived unit contains undeclared units

$$v_{19} = \mathrm{vol}\,(\mathrm{COMpartment}) \cdot \mathrm{r} \cdot [\mathrm{m\_2}] \tag{61}$$

8.20 Reaction Naive_CTL_division_4

This is an irreversible reaction of one reactant forming one product.

Name Naive CTL division 4

Reaction equation

$$\mathrm{m\_3} \longrightarrow 2\,\mathrm{m\_4} \tag{62}$$

Reactant

Table 39: Properties of each reactant.

Id	Name	SBO
m_3	m_3	

Product

Table 40: Properties of each product.

Id	Name	SBO
m_4	m_4	

Kinetic Law

Derived unit contains undeclared units

$$v_{20} = \mathrm{vol}\,(\mathrm{COMpartment}) \cdot \mathrm{r} \cdot [\mathrm{m\_3}] \tag{63}$$

8.21 Reaction Naive_CTL_division_5

This is an irreversible reaction of one reactant forming one product.

Name Naive CTL division 5

Reaction equation

$$\mathrm{m\_4} \longrightarrow 2\,\mathrm{m\_5} \tag{64}$$

Reactant

Table 41: Properties of each reactant.

Id	Name	SBO
m_4	m_4	

Product

Table 42: Properties of each product.

Id	Name	SBO
m_5	m_5	

Kinetic Law

Derived unit contains undeclared units

$$v_{21} = \mathrm{vol}\,(\mathrm{COMpartment}) \cdot \mathrm{r} \cdot [\mathrm{m\_4}] \tag{65}$$

8.22 Reaction Naive_CTL_division_6

This is an irreversible reaction of one reactant forming one product.

Name Naive CTL division 6

Reaction equation

$$\mathrm{m\_5} \longrightarrow 2\,\mathrm{m\_6} \tag{66}$$

Reactant

Table 43: Properties of each reactant.

Id	Name	SBO
m_5	m_5	

Product

Table 44: Properties of each product.

Id	Name	SBO
m_6	m_6	

Kinetic Law

Derived unit contains undeclared units

$$v_{22} = \mathrm{vol}\,(\mathrm{COMpartment}) \cdot \mathrm{r} \cdot [\mathrm{m\_5}] \tag{67}$$

8.23 Reaction Naive_CTL_division_7

This is an irreversible reaction of one reactant forming one product.

Name Naive CTL division 7

Reaction equation

$$\mathrm{m\_6} \longrightarrow 2\,\mathrm{m\_7} \tag{68}$$

Reactant

Table 45: Properties of each reactant.

Id	Name	SBO
m_6	m_6	

Product

Table 46: Properties of each product.

Id	Name	SBO
m_7	m_7	

Kinetic Law

Derived unit contains undeclared units

$$v_{23} = \mathrm{vol}\,(\mathrm{COMpartment}) \cdot \mathrm{r} \cdot [\mathrm{m\_6}] \tag{69}$$

8.24 Reaction Naive_CTL_division_8

This is an irreversible reaction of one reactant forming one product.

Name Naive CTL division 8

Reaction equation

$$\mathrm{m\_7} \longrightarrow 2\,\mathrm{m\_8} \tag{70}$$

Reactant

Table 47: Properties of each reactant.

Id	Name	SBO
m_7	m_7	

Product

Table 48: Properties of each product.

Id	Name	SBO
m_8	m_8	

Kinetic Law

Derived unit contains undeclared units

$$v_{24} = \mathrm{vol}\,(\mathrm{COMpartment}) \cdot \mathrm{r} \cdot [\mathrm{m\_7}] \tag{71}$$

8.25 Reaction Precursor_T_cell_differentiation_1

This is an irreversible reaction of one reactant forming no product.

Name Precursor T-cell differentiation 1

Reaction equation

$$\mathrm{m\_8} \longrightarrow \emptyset \tag{72}$$

Reactant

Table 49: Properties of each reactant.

Id	Name	SBO
m_8	m_8	

Kinetic Law

Derived unit contains undeclared units

$$v_{25} = \mathrm{vol}\,(\mathrm{COMpartment}) \cdot \mathrm{r} \cdot [\mathrm{m\_8}] \tag{73}$$

8.26 Reaction NK_cell_production

This is an irreversible reaction of no reactant forming one product.

Name NK cell production

Reaction equation

$$\emptyset \longrightarrow \mathrm{z\_i} \tag{74}$$

Product

Table 50: Properties of each product.

Id	Name	SBO
z_i	z_i	

Kinetic Law

Derived unit contains undeclared units

$$v_{26} = \mathrm{vol}\left(\mathrm{COMpartment}\right) \cdot \mathrm{Constant\_flux\_\_irreversible}\left(\mathrm{xi}\right) \tag{75}$$

$$\mathrm{Constant\_flux\_\_irreversible}\left(\left[\mathrm{v}\right]\right) = \left[\mathrm{v}\right] \tag{76}$$

$$\mathrm{Constant\_flux\_\_irreversible}\left(\left[\mathrm{v}\right]\right) = \left[\mathrm{v}\right] \tag{77}$$

8.27 Reaction `NK_infection_induced_production`

This is an irreversible reaction of no reactant forming one product influenced by two modifiers.

Name NK infection-induced production

Reaction equation

$$\emptyset \xrightarrow{\mathrm{y\_0},\ \mathrm{y\_1}} \mathrm{z\_i} \tag{78}$$

Modifiers

Table 51: Properties of each modifier.

Id	Name	SBO
y_0	y_0	
y_1	y_1	

Product

Table 52: Properties of each product.

Id	Name	SBO
z_i	z_i	

Kinetic Law

Derived unit contains undeclared units

$$v_{27} = \mathrm{vol}\left(\mathrm{COMpartment}\right) \cdot \mathrm{function\_4}\left(\mathrm{ci}, \left[\mathrm{y\_0}\right], \left[\mathrm{y\_1}\right], \left[\mathrm{z\_i}\right]\right) \tag{79}$$

$$\text{function\_4}(\text{c\_i}, \text{y0}, \text{y1}, \text{zi}) = \text{c\_i} \cdot (\text{y0} + \text{y1}) \cdot \text{zi} \tag{80}$$

$$\text{function\_4}(\text{c\_i}, \text{y0}, \text{y1}, \text{zi}) = \text{c\_i} \cdot (\text{y0} + \text{y1}) \cdot \text{zi} \tag{81}$$

8.28 Reaction NK_cell_death

This is an irreversible reaction of one reactant forming no product.

Name NK cell death

Reaction equation

$$\text{z\_i} \longrightarrow \emptyset \tag{82}$$

Reactant

Table 53: Properties of each reactant.

Id	Name	SBO
z_i	z_i	

Kinetic Law

Derived unit contains undeclared units

$$v_{28} = \text{vol}(\text{COMpartment}) \cdot \text{bi} \cdot [\text{z\_i}] \tag{83}$$

8.29 Reaction NK_induced_infected_cell_death_1

This is an irreversible reaction of one reactant forming no product influenced by one modifier.

Name NK-induced infected cell death 1

Reaction equation

$$\text{y\_0} \xrightarrow{\text{z\_i}} \emptyset \tag{84}$$

Reactant

Table 54: Properties of each reactant.

Id	Name	SBO
y_0	y_0	

Modifier

Table 55: Properties of each modifier.

Id	Name	SBO
z_i	z_i	

Kinetic Law

Derived unit contains undeclared units

$$v_{29} = \mathrm{vol}\left(\mathrm{COMpartment}\right) \cdot \mathrm{function}\left(\mathrm{p\_i}, [\mathrm{z\_i}], [\mathrm{y\_0}]\right) \tag{85}$$

$$\mathrm{function}\left(\mathrm{parameter}, \mathrm{modifier}, \mathrm{substrate}\right) = \mathrm{parameter} \cdot \mathrm{modifier} \cdot \mathrm{substrate} \tag{86}$$

$$\mathrm{function}\left(\mathrm{parameter}, \mathrm{modifier}, \mathrm{substrate}\right) = \mathrm{parameter} \cdot \mathrm{modifier} \cdot \mathrm{substrate} \tag{87}$$

8.30 Reaction NK_induced_infected_cell_death_2

This is an irreversible reaction of one reactant forming no product influenced by one modifier.

Name NK-induced infected cell death 2

Reaction equation

$$\mathrm{y\_1} \xrightarrow{\mathrm{z\_i}} \emptyset \tag{88}$$

Reactant

Table 56: Properties of each reactant.

Id	Name	SBO
y_1	y_1	

Modifier

Table 57: Properties of each modifier.

Id	Name	SBO
z_i	z_i	

Kinetic Law

Derived unit contains undeclared units

$$v_{30} = \mathrm{vol}\,(\mathrm{COMpartment}) \cdot \mathrm{function}\,(\mathrm{p\_i}, [\mathrm{z\_i}], [\mathrm{y\_1}]) \tag{89}$$

$$\mathrm{function}\,(\mathrm{parameter}, \mathrm{modifier}, \mathrm{substrate}) = \mathrm{parameter} \cdot \mathrm{modifier} \cdot \mathrm{substrate} \tag{90}$$

$$\mathrm{function}\,(\mathrm{parameter}, \mathrm{modifier}, \mathrm{substrate}) = \mathrm{parameter} \cdot \mathrm{modifier} \cdot \mathrm{substrate} \tag{91}$$

9 Derived Rate Equations

When interpreted as an ordinary differential equation framework, this model implies the following set of equations for the rates of change of each species.

Identifiers for kinetic laws highlighted in gray cannot be verified to evaluate to units of SBML `substance` per `time`. As a result, some SBML interpreters may not be able to verify the consistency of the units on quantities in the model. Please check if

- parameters without an unit definition are involved or
- volume correction is necessary because the `hasOnlySubstanceUnits` flag may be set to `false` and `spacialDimensions`> 0 for certain species.

9.1 Species x

Name x

Initial concentration $1\ \mathrm{mol} \cdot \mathrm{l}^{-1}$

This species takes part in four reactions (as a reactant in Host_cell_death, Infection_1, Infection_2 and as a product in Host_cell_proliferation).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{x} = v_1 - v_2 - v_3 - v_4 \tag{92}$$

9.2 Species y_0

Name y_0

Initial concentration $0\ \mathrm{mol}\cdot\mathrm{l}^{-1}$

This species takes part in eight reactions (as a reactant in Infected_cell_death_1, Infected_cell_infection_progression_1, CTL_induced_infected_cell_death_1, NK_induced_infected_cell_death_1 and as a product in Infection_1, Infected_cell_infection_progression_2 and as a modifier in Infection_induced_CTL_proliferation_stimulation, NK_infection_induced_production).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{y\_0} = v_3 + v_7 - v_5 - v_6 - v_8 - v_{29} \tag{93}$$

9.3 Species y_1

Name y_1

Initial concentration $0\ \mathrm{mol}\cdot\mathrm{l}^{-1}$

This species takes part in seven reactions (as a reactant in Infected_cell_death_2, CTL_induced_infected_cell_death_2, NK_induced_infected_cell_death_2 and as a product in Infected_cell_infection_progression_1 and as a modifier in Virus_particle_production, Infection_induced_CTL_proliferation_stimulation, NK_infection_induced_production).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{y\_1} = v_6 - v_9 - v_{10} - v_{30} \tag{94}$$

9.4 Species L

Name L

Initial concentration $0\ \mathrm{mol}\cdot\mathrm{l}^{-1}$

This species takes part in three reactions (as a reactant in Infected_cell_infection_progression_2, Infected_cell_death_3 and as a product in Infection_2).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{L} = v_4 - v_7 - v_{11} \tag{95}$$

9.5 Species v

Name v

Initial concentration $1\ \mathrm{mol}\cdot\mathrm{l}^{-1}$

This species takes part in four reactions (as a reactant in Viral_particle_degradation and as a product in Virus_particle_production and as a modifier in Infection_1, Infection_2).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{v} = v_{12} - v_{13} \tag{96}$$

9.6 Species z_a

Name z_a

Initial concentration $1\ \mathrm{mol}\cdot\mathrm{l}^{-1}$

This species takes part in five reactions (as a reactant in CTL_cell_death and as a product in Precursor_T_cell_differentiation_2, Infection_induced_CTL_proliferation_stimulation and as a modifier in CTL_induced_infected_cell_death_1, CTL_induced_infected_cell_death_2).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{z\_a} = v_{14} + v_{15} - v_{16} \tag{97}$$

9.7 Species m_0

Name m_0

Initial concentration $0\ \mathrm{mol}\cdot\mathrm{l}^{-1}$

This species takes part in one reaction (as a reactant in Naive_CTL_division_1).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{m\_0} = -v_{17} \tag{98}$$

9.8 Species m_1

Name m_1

Initial concentration $0\ \mathrm{mol}\cdot\mathrm{l}^{-1}$

This species takes part in two reactions (as a reactant in Naive_CTL_division_2 and as a product in Naive_CTL_division_1).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{m\_1} = 2\,v_{17} - v_{18} \tag{99}$$

9.9 Species m_2

Name m_2

Initial concentration $0\ \mathrm{mol}\cdot\mathrm{l}^{-1}$

This species takes part in two reactions (as a reactant in Naive_CTL_division_3 and as a product in Naive_CTL_division_2).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{m\_2} = 2\,v_{18} - v_{19} \tag{100}$$

9.10 Species m_3

Name m_3

Initial concentration $0\ \mathrm{mol}\cdot\mathrm{l}^{-1}$

This species takes part in two reactions (as a reactant in Naive_CTL_division_4 and as a product in Naive_CTL_division_3).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{m\_3} = 2\,v_{19} - v_{20} \tag{101}$$

9.11 Species m_4

Name m_4

Initial concentration $0\ \mathrm{mol}\cdot\mathrm{l}^{-1}$

This species takes part in two reactions (as a reactant in Naive_CTL_division_5 and as a product in Naive_CTL_division_4).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{m\_4} = 2\,v_{20} - v_{21} \tag{102}$$

9.12 Species m_5

Name m_5

Initial concentration $0\ \mathrm{mol}\cdot\mathrm{l}^{-1}$

This species takes part in two reactions (as a reactant in Naive_CTL_division_6 and as a product in Naive_CTL_division_5).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{m\_5} = 2\,v_{21} - v_{22} \tag{103}$$

9.13 Species m_6

Name m_6

Initial concentration $0\ \mathrm{mol}\cdot\mathrm{l}^{-1}$

This species takes part in two reactions (as a reactant in Naive_CTL_division_7 and as a product in Naive_CTL_division_6).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{m\_6} = 2\,v_{22} - v_{23} \tag{104}$$

9.14 Species m_7

Name m_7

Initial concentration $0\ \mathrm{mol}\cdot\mathrm{l}^{-1}$

This species takes part in two reactions (as a reactant in Naive_CTL_division_8 and as a product in Naive_CTL_division_7).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{m\_7} = 2\,v_{23} - v_{24} \tag{105}$$

9.15 Species m_8

Name m_8

Initial concentration $0\ \mathrm{mol}\cdot\mathrm{l}^{-1}$

This species takes part in three reactions (as a reactant in Precursor_T_cell_differentiation_1 and as a product in Naive_CTL_division_8 and as a modifier in Precursor_T_cell_differentiation_2).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{m\_8} = 2\,v_{24} - v_{25} \tag{106}$$

9.16 Species z_i

Name z_i

Initial concentration $0.1\ \mathrm{mol}\cdot\mathrm{l}^{-1}$

This species takes part in five reactions (as a reactant in NK_cell_death and as a product in NK_cell_production, NK_infection_induced_production and as a modifier in NK_induced_infected_cell_death_1, NK_induced_infected_cell_death_2).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{z\_i} = v_{26} + v_{27} - v_{28} \tag{107}$$

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