BioDose and Chemistry actors in GATE 10

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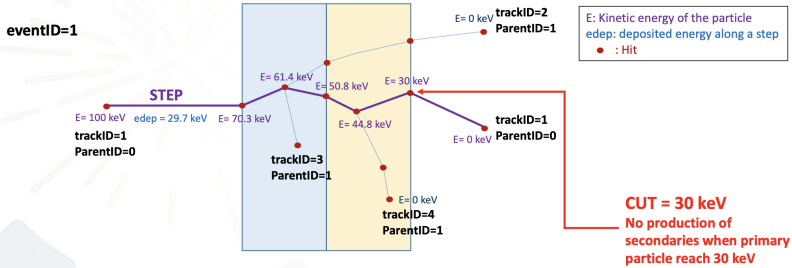
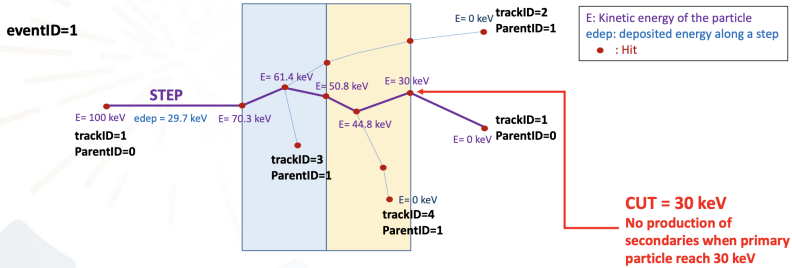
GATE



	Geant4 actions					
	`BeginOfRun`	`BeginOfEvent`	`Stepping`	`EndOfEvent`	`EndOfRun`	`NewStage`
compute dose	✓		✓		✓	
compute fluence	✓	✓	✓		✓	
compute biodose	✓	✓	✓	✓	✓	
apply chemistry				✓	✓	✓

GATE



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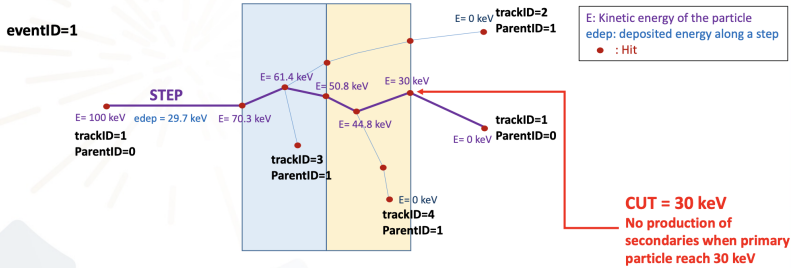
compute biodose	✓	✓	✓	✓	✓	
apply chemistry				✓	✓	✓

GATE



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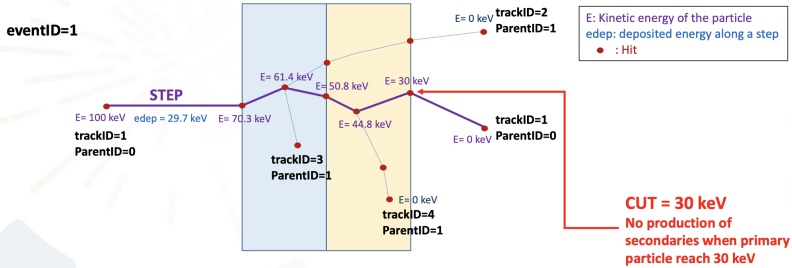
apply chemistry				✓	✓	✓

GATE



	Geant4 actions					
GATE actors ↓	`BeginOfRun`	`BeginOfEvent`	`Stepping`	`EndOfEvent`	`EndOfRun`	`NewStage`
DoseActor	✓		✓		✓	
FluenceActor	✓	✓	✓		✓	
BioDoseActor	✓	✓	✓	✓	✓	
ChemistryActor				✓	✓	✓

Biological dose

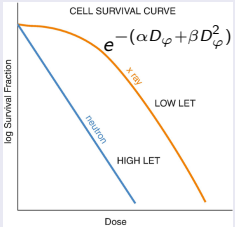
Objective of the biological dose

effects of the physical dose on biological tissues

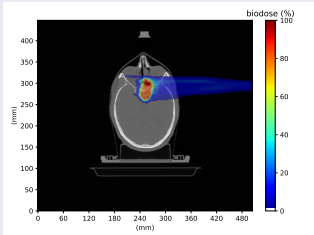
nano/micro scale

- mMKM
  (Kase et al., 2006)
- NanOx
  (Cunha et al., 2017)

cellular scale



macro scale



Biophysical model databases

Cell line Human Salivary Glands (HSG): `HSG_mMKM.db` or `HSG_NanOx.db`
$\Longrightarrow$ easy to provide new cell lines or biophysical models

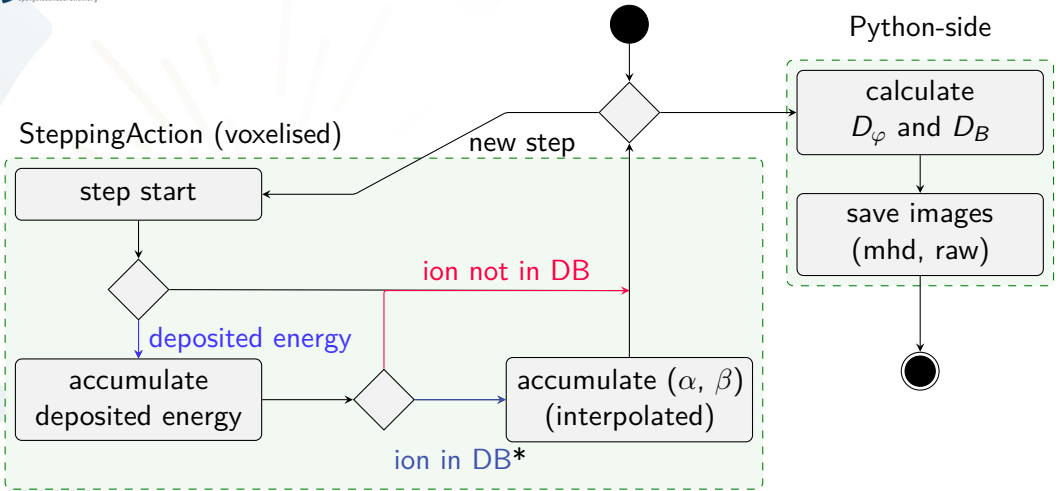
Example:

α, β: from Geant4-DNA/LPCHEM simulations

```
// Ion type

H
...
He
...
C
...
O
...
Li
...
```

```
// energy   alpha    beta
// (MeV)    (Gy-1)   (Gy-2)
H
0.1         3.528    0.059
0.125       3.584    0.022
0.15        3.642    0.098
...
1           0.932    0.059
...
10          0.376    0.063
...
300         0.339    0.109
```

BioDoseActor process diagram



* our database (DB) contains values for {H, He, C, O, Li}

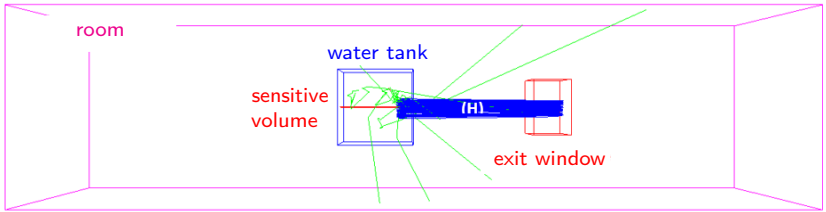
User interface

```
biodose = sim.add_actor("BioDoseActor", "biodose")

biodose.attached_to          = volume
biodose.output_filename      = "biodose.mhd"
biodose.translation          = [0, 0, 0]
biodose.spacing              = [1 * mm, 60 * mm, 60 * mm]
biodose.size                 = [400, 1, 1]

biodose.cell_line            = "HSG"
biodose.biophysical_model    = "NanOx"
biodose.alpha_ref            = 0.313
biodose.beta_ref             = 0.0615
biodose.uncertainty.active   = True
```

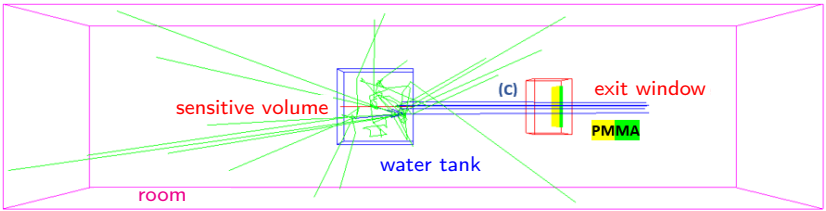
H/C-ion SOBP clinical PBS beams in water

- Human Salivary Glands
- Pencil Beam Scanning:
  - H: 95.9 – 113 MeV
  - C: 120 – 402 MeV/u
- Water box: $400 \times 400 \times 400$ mm^3
- Sensitive volume: $400 \times 60 \times 60$ mm^3
- Voxel size: $1 \times 60 \times 60$ mm^3
- PhysicsList:
  - H: `QGSP_BIC_EMZ`
  - C: `Shielding_EMZ`
- multiple stepfunctions
- multiple steplimiters

H-ion:



C-ion:



Results – dose profiles

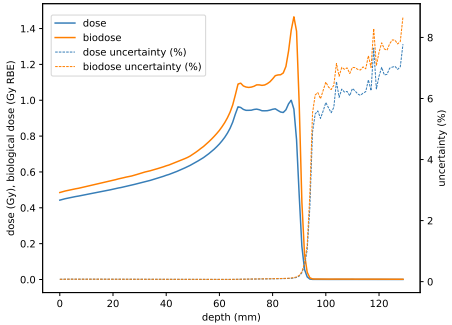


Figure: H-ion in water with 1×10^7 primaries, production cut 100 m, step limiter 10 µm (HSG, NanOx)

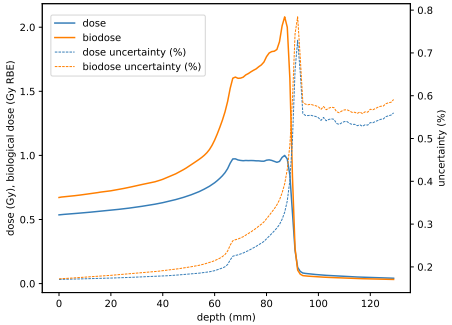
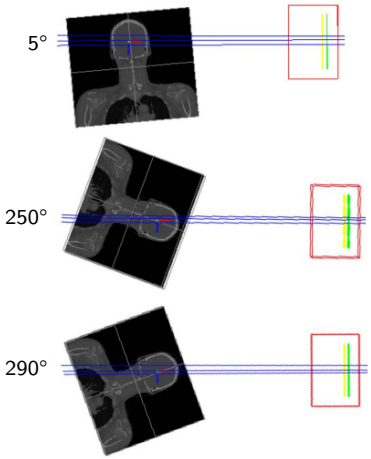


Figure: C-ion in water with 1×10^6 primaries, production cut 100 m, step limiter 10 µm (HSG, mMKM)

C-ion clinical PBS beams in patient

- Human Salivary Glands
- Pencil Beam Scanning
- CT: $50 \times 50 \times 44$ cm^3
- Voxel size: $0.97 \times 0.97 \times 2$ mm^3
- PhysicsList: `Shielding_EMZ`
- 3 beams
- sinonasal chordoma



Results – C-ion, biological dose (NanOx)

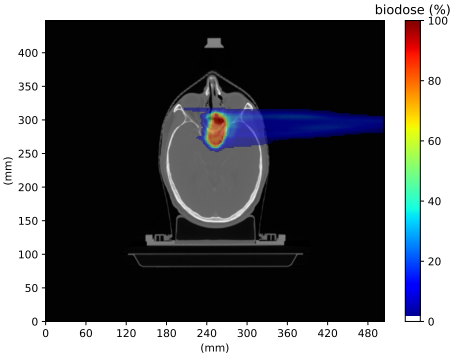


Figure: biological dose with C-ion in patient, 1×10^6 primaries per beam, production cut 100 m, step limiter 10 µm (HSG, NanOx)

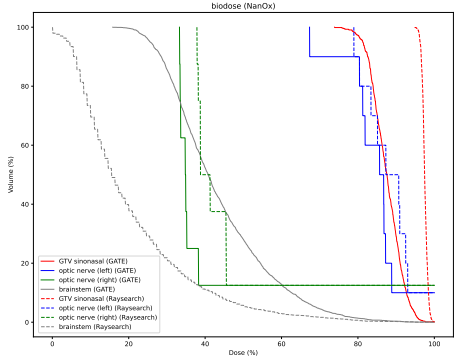


Figure: Cumulative biological DVH comparison GATE/NanOx (solid lines) and Raysearch (dashed lines)

Chemistry actor

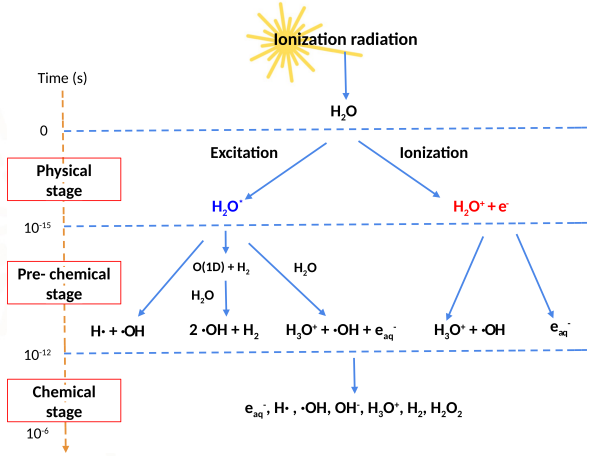


Figure from Da Eun Kwon

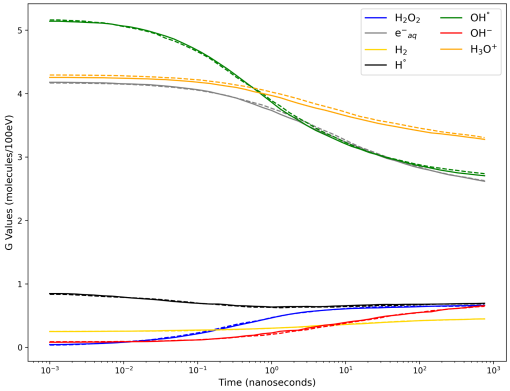
Chemistry actor – interface

```
chemistry = sim.add_actor("ChemistryActor", "chemistry")
chemistry.attached_to     = volume
chemistry.timestep_model  = "IRT"  # or "SBS"
chemistry.end_time        = 1 * ns
chemistry.time_bins_count = 50
chemistry.reactions       = [
  # totally diffusion-controlled (TDC)
  [["H", "H"], ["H2"], "Fix", 0.5e10, 0],
  [["e_aq", "H"], ["H2", "OHm"], "Fix", 2.5e10, 0],
  [["e_aq", "e_aq"], ["H2", "OHm", "OHm"], "Fix", 0.636e10, 0],
  [["H3Op", "OHm"], ["H2O"], "Fix", 1.13e11, 0],
  # partially diffusion-controlled (PDC)
  [["OH", "H"], ["H2O"], "Fix", 1.55e10, 1],
  # ...
]
```

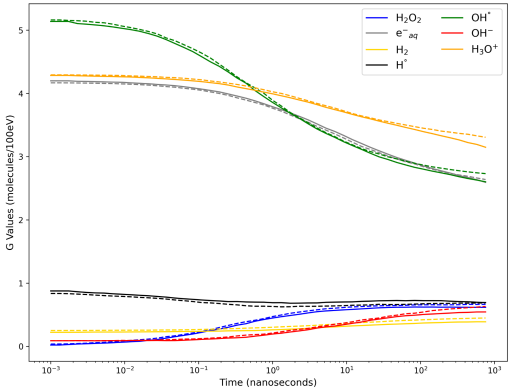
Chemistry actor – results

Geant4-DNA (chem6) dashed; GATE 10 plain

IRT (Independent Reaction Time)



SBS (Step by Step)



Simulation and analysis by Da Eun Kwon

Conclusion

BioDose actor

- available in current GATE release (9.4)
- will be available with next GATE release (10)

Chemistry actor

- still work in progress
- first version for end of 2024