Chapter 11.6 of
Book For Application Developers

Release 10.6

Geant4 Collaboration

Rev4.1 - August 11th, 2020

demos/water_phantom An example of "water phantom dosimetry". This demo program shows that a GEANT4 application well coworks with Root on Python front end. VisManager, PrimaryGeneratorAction, UserAction-s, histogramming with Root are implemented in Python;

- dose calculation in a water phantom
- Python overloading of user actions
- on-line histogramming with Root
- visualization

education Educational examples with Graphical User Interface using `TKinter`

- lesson1
  The first version of the courseware of the mass attenuation coefficient.
- lesson2
  GUI interface of ExN03, which can control geometry configuration, initial particle condition, physics processes, cut value, magnetic field and visualization outputs.

emplot Examples of plotting photon cross sections and stopping powers with Root.

gdml Examples of writing/reading user's geometry to/from a GDML file

11.6 GEANT4 Material Database

11.6.1 Simple Materials (Elements)

Z	Name	density(g/cm^3)	I(eV)
1	G4_H	8.3748e-05	19.2
2	G4_He	0.000166322	41.8
3	G4_Li	0.534	40
4	G4_Be	1.848	63.7
5	G4_B	2.37	76
6	G4_C	2	81
7	G4_N	0.0011652	82
8	G4_O	0.00133151	95
9	G4_F	0.00158029	115
10	G4_Ne	0.000838505	137
11	G4_Na	0.971	149
12	G4_Mg	1.74	156
13	G4_Al	2.699	166
14	G4_Si	2.33	173
15	G4_P	2.2	173
16	G4_S	2	180
17	G4_Cl	0.00299473	174
18	G4_Ar	0.00166201	188
19	G4_K	0.862	190
20	G4_Ca	1.55	191
21	G4_Sc	2.989	216
22	G4_Ti	4.54	233
23	G4_V	6.11	245
24	G4_Cr	7.18	257
25	G4_Mn	7.44	272
26	G4_Fe	7.874	286
27	G4_Co	8.9	297
28	G4_Ni	8.902	311

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Table 11.1 – continued from previous page

Z	Name	density(g/cm^3)	I(eV)
29	G4_Cu	8.96	322
30	G4_Zn	7.133	330
31	G4_Ga	5.904	334
32	G4_Ge	5.323	350
33	G4_As	5.73	347
34	G4_Se	4.5	348
35	G4_Br	0.0070721	343
36	G4_Kr	0.00347832	352
37	G4_Rb	1.532	363
38	G4_Sr	2.54	366
39	G4_Y	4.469	379
40	G4_Zr	6.506	393
41	G4_Nb	8.57	417
42	G4_Mo	10.22	424
43	G4_Tc	11.5	428
44	G4_Ru	12.41	441
45	G4_Rh	12.41	449
46	G4_Pd	12.02	470
47	G4_Ag	10.5	470
48	G4_Cd	8.65	469
49	G4_In	7.31	488
50	G4_Sn	7.31	488
51	G4_Sb	6.691	487
52	G4_Te	6.24	485
53	G4_I	4.93	491
54	G4_Xe	0.00548536	482
55	G4_Cs	1.873	488
56	G4_Ba	3.5	491
57	G4_La	6.154	501
58	G4_Ce	6.657	523
59	G4_Pr	6.71	535
60	G4_Nd	6.9	546
61	G4_Pm	7.22	560
62	G4_Sm	7.46	574
63	G4_Eu	5.243	580
64	G4_Gd	7.9004	591
65	G4_Tb	8.229	614
66	G4_Dy	8.55	628
67	G4_Ho	8.795	650
68	G4_Er	9.066	658
69	G4_Tm	9.321	674
70	G4_Yb	6.73	684
71	G4_Lu	9.84	694
72	G4_Hf	13.31	705
73	G4_Ta	16.654	718
74	G4_W	19.3	727
75	G4_Re	21.02	736
76	G4_Os	22.57	746
77	G4_Ir	22.42	757

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Table 11.1 – continued from previous page

Z	Name	density(g/cm^3)	I(eV)
78	G4_Pt	21.45	790
79	G4_Au	19.32	790
80	G4_Hg	13.546	800
81	G4_Tl	11.72	810
82	G4_Pb	11.35	823
83	G4_Bi	9.747	823
84	G4_Po	9.32	830
85	G4_At	9.32	825
86	G4_Rn	0.00900662	794
87	G4_Fr	1	827
88	G4_Ra	5	826
89	G4_Ac	10.07	841
90	G4_Th	11.72	847
91	G4_Pa	15.37	878
92	G4_U	18.95	890
93	G4_Np	20.25	902
94	G4_Pu	19.84	921
95	G4_Am	13.67	934
96	G4_Cm	13.51	939
97	G4_Bk	14	952
98	G4_Cf	10	966

11.6.2 NIST Compounds

```
============================================================
 Ncomp             Name      density(g/cm^3)  I(eV) ChFormula
============================================================
 6            G4_A-150_TISSUE      1.127      65.1
         1      0.101327
         6        0.7755
         7      0.035057
         8     0.0523159
         9      0.017422
        20      0.018378
 3               G4_ACETONE     0.7899      64.2
         6             3
         1             6
         8             1
 2             G4_ACETYLENE  0.0010967      58.2
         6             2
         1             2
 3               G4_ADENINE        1.6      71.4
         6             5
         1             5
         7             5
 7     G4_ADIPOSE_TISSUE_ICRP       0.95      63.2
         1         0.114
         6         0.598
         7         0.007
         8         0.278
        11         0.001
        16         0.001
        17         0.001
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```
 4                   G4_AIR 0.00120479      85.7
         6      0.000124
         7      0.755268
         8      0.231781
        18      0.012827
 4                G4_ALANINE       1.42      71.9
         6               3
         1               7
         7               1
         8               2
 2           G4_ALUMINUM_OXIDE       3.97     145.2   Al_2O_3
        13               2
         8               3
 3                 G4_AMBER        1.1      63.2
         1       0.10593
         6      0.788974
         8      0.105096
 2                G4_AMMONIA 0.000826019      53.7
         7               1
         1               3
 3                G4_ANILINE     1.0235      66.2
         6               6
         1               7
         7               1
 2             G4_ANTHRACENE      1.283      69.5
         6              14
         1              10
 6             G4_B-100_BONE       1.45      85.9
         1     0.0654709
         6      0.536944
         7        0.0215
         8      0.032085
         9      0.167411
        20      0.176589
 3                G4_BAKELITE       1.25      72.4
         1      0.057441
         6      0.774591
         8      0.167968
 2          G4_BARIUM_FLUORIDE       4.89     375.9
        56               1
         9               2
 3           G4_BARIUM_SULFATE        4.5     285.7
        56               1
        16               1
         8               4
 2                G4_BENZENE    0.87865      63.4
         6               6
         1               6
 2          G4_BERYLLIUM_OXIDE       3.01      93.2
         4               1
         8               1
 3                   G4_BGO       7.13     534.1
        83               4
        32               3
         8              12
10             G4_BLOOD_ICRP       1.06      75.2
         1         0.102
         6          0.11
         7         0.033
         8         0.745
        11         0.001
        15         0.001
        16         0.002
        17         0.003
        19         0.002
        26         0.001
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```
8       G4_BONE_COMPACT_ICRU       1.85      91.9
        1         0.064
        6         0.278
        7         0.027
        8          0.41
       12         0.002
       15          0.07
       16         0.002
       20         0.147
9      G4_BONE_CORTICAL_ICRP       1.92       110
        1         0.034
        6         0.155
        7         0.042
        8         0.435
       11         0.001
       12         0.002
       15         0.103
       16         0.003
       20         0.225
2           G4_BORON_CARBIDE       2.52      84.7
        5             4
        6             1
2             G4_BORON_OXIDE      1.812      99.6
        5             2
        8             3
9              G4_BRAIN_ICRP       1.04      73.3
        1         0.107
        6         0.145
        7         0.022
        8         0.712
       11         0.002
       15         0.004
       16         0.002
       17         0.003
       19         0.003
2                 G4_BUTANE 0.00249343      48.3
        6             4
        1            10
3         G4_N-BUTYL_ALCOHOL     0.8098      59.9
        6             4
        1            10
        8             1
5                 G4_C-552       1.76      86.8
        1       0.02468
        6      0.501611
        8      0.004527
        9      0.465209
       14      0.003973
2       G4_CADMIUM_TELLURIDE        6.2     539.3
       48             1
       52             1
3       G4_CADMIUM_TUNGSTATE        7.9     468.3
       48             1
       74             1
        8             4
3       G4_CALCIUM_CARBONATE        2.8     136.4
       20             1
        6             1
        8             3
2        G4_CALCIUM_FLUORIDE       3.18       166
       20             1
        9             2
2           G4_CALCIUM_OXIDE        3.3     176.1
       20             1
        8             1
3         G4_CALCIUM_SULFATE       2.96     152.3
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```
       20             1
       16             1
        8             4
 3      G4_CALCIUM_TUNGSTATE      6.062       395
       20             1
       74             1
        8             4
 2         G4_CARBON_DIOXIDE 0.00184212        85   CO_2
        6             1
        8             2
 2    G4_CARBON_TETRACHLORIDE      1.594     166.3
        6             1
       17             4
 3    G4_CELLULOSE_CELLOPHANE       1.42      77.6
        6             6
        1            10
        8             5
 3      G4_CELLULOSE_BUTYRATE        1.2      74.6
        1      0.067125
        6      0.545403
        8      0.387472
 4       G4_CELLULOSE_NITRATE       1.49        87
        1      0.029216
        6      0.271296
        7      0.121276
        8      0.578212
 5           G4_CERIC_SULFATE       1.03      76.7
        1      0.107596
        7        0.0008
        8      0.874976
       16      0.014627
       58      0.002001
 2         G4_CESIUM_FLUORIDE      4.115     440.7
       55             1
        9             1
 2           G4_CESIUM_IODIDE       4.51     553.1
       55             1
       53             1
 3           G4_CHLOROBENZENE     1.1058      89.1
        6             6
        1             5
       17             1
 3              G4_CHLOROFORM     1.4832       156
        6             1
        1             1
       17             3
10               G4_CONCRETE        2.3     135.2
        1          0.01
        6         0.001
        8      0.529107
       11         0.016
       12         0.002
       13      0.033872
       14      0.337021
       19         0.013
       20         0.044
       26         0.014
 2             G4_CYCLOHEXANE      0.779      56.4
        6             6
        1            12
 3     G4_1,2-DICHLOROBENZENE     1.3048     106.5
        6             6
        1             4
       17             2
 4   G4_DICHLORODIETHYL_ETHER     1.2199     103.3
        6             4
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```
        1             8
        8             1
       17             2
3      G4_1,2-DICHLOROETHANE     1.2351     111.9
        6             2
        1             4
       17             2
3           G4_DIETHYL_ETHER    0.71378         60
        6             4
        1            10
        8             1
4  G4_N,N-DIMETHYL_FORMAMIDE     0.9487      66.6
        6             3
        1             7
        7             1
        8             1
4      G4_DIMETHYL_SULFOXIDE     1.1014      98.6
        6             2
        1             6
        8             1
       16             1
2                 G4_ETHANE 0.00125324      45.4
        6             2
        1             6
3           G4_ETHYL_ALCOHOL     0.7893      62.9
        6             2
        1             6
        8             1
3         G4_ETHYL_CELLULOSE       1.13      69.3
        1      0.090027
        6      0.585182
        8      0.324791
2               G4_ETHYLENE 0.00117497      50.7
        6             2
        1             4
8           G4_EYE_LENS_ICRP       1.07      73.3
        1         0.096
        6         0.195
        7         0.057
        8         0.646
       11         0.001
       15         0.001
       16         0.003
       17         0.001
2            G4_FERRIC_OXIDE        5.2     227.3
       26             2
        8             3
2              G4_FERROBORIDE       7.15       261
       26             1
        5             1
2           G4_FERROUS_OXIDE        5.7     248.6
       26             1
        8             1
7         G4_FERROUS_SULFATE      1.024      76.4
        1      0.108259
        7       2.7e-05
        8      0.878636
       11       2.2e-05
       16      0.012968
       17       3.4e-05
       26       5.4e-05
3               G4_FREON-12       1.12       143
        6      0.099335
        9      0.314247
       17      0.586418
3               G4_FREON-12B2        1.8     284.9
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```
        6      0.057245
        9      0.181096
       35      0.761659
3               G4_FREON-13       0.95     126.6
        6      0.114983
        9      0.545621
       17      0.339396
3              G4_FREON-13B1        1.5     210.5
        6             1
        9             3
       35             1
3              G4_FREON-13I1        1.8     293.5
        6      0.061309
        9      0.290924
       53      0.647767
3   G4_GADOLINIUM_OXYSULFIDE       7.44     493.3
       64             2
        8             2
       16             1
2        G4_GALLIUM_ARSENIDE       5.31     384.9
       31             1
       33             1
5      G4_GEL_PHOTO_EMULSION     1.2914      74.8
        1       0.08118
        6       0.41606
        7       0.11124
        8       0.38064
       16       0.01088
6             G4_Pyrex_Glass       2.23       134
        5     0.0400639
        8      0.539561
       11     0.0281909
       13      0.011644
       14      0.377219
       19    0.00332099
5               G4_GLASS_LEAD       6.22     526.4
        8      0.156453
       14      0.080866
       22      0.008092
       33      0.002651
       82      0.751938
4             G4_GLASS_PLATE        2.4     145.4
        8        0.4598
       11     0.0964411
       14      0.336553
       20      0.107205
4               G4_GLUTAMINE       1.46      73.3
        6             5
        1            10
        7             2
        8             3
3                G4_GLYCEROL     1.2613      72.6
        6             3
        1             8
        8             3
4                 G4_GUANINE        2.2        75
        6             5
        1             5
        7             5
        8             1
4                 G4_GYPSUM       2.32     129.7
       20             1
       16             1
        8             6
        1             4
2               G4_N-HEPTANE    0.68376      54.4
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```
        6             7
        1            16
2              G4_N-HEXANE     0.6603        54
        6             6
        1            14
4                G4_KAPTON       1.42      79.6
        6            22
        1            10
        7             2
        8             5
3    G4_LANTHANUM_OXYBROMIDE       6.28     439.7
       57             1
       35             1
        8             1
3    G4_LANTHANUM_OXYSULFIDE       5.86     421.2
       57             2
        8             2
       16             1
2             G4_LEAD_OXIDE       9.53     766.7
        8      0.071682
       82      0.928318
3          G4_LITHIUM_AMIDE      1.178      55.5
        3             1
        7             1
        1             2
3       G4_LITHIUM_CARBONATE       2.11      87.9
        3             2
        6             1
        8             3
2        G4_LITHIUM_FLUORIDE      2.635        94
        3             1
        9             1
2          G4_LITHIUM_HYDRIDE       0.82      36.5
        3             1
        1             1
2           G4_LITHIUM_IODIDE      3.494     485.1
        3             1
       53             1
2            G4_LITHIUM_OXIDE      2.013      73.6
        3             2
        8             1
3     G4_LITHIUM_TETRABORATE       2.44      94.6
        3             2
        5             4
        8             7
9              G4_LUNG_ICRP       1.04      75.3
        1         0.105
        6         0.083
        7         0.023
        8         0.779
       11         0.002
       15         0.001
       16         0.002
       17         0.003
       19         0.002
5                 G4_M3_WAX       1.05      67.9
        1      0.114318
        6      0.655824
        8     0.0921831
       12      0.134792
       20      0.002883
3     G4_MAGNESIUM_CARBONATE      2.958       118
       12             1
        6             1
        8             3
2      G4_MAGNESIUM_FLUORIDE          3     134.3
```

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```
       12             1
        9             2
2         G4_MAGNESIUM_OXIDE       3.58     143.8
       12             1
        8             1
3   G4_MAGNESIUM_TETRABORATE       2.53     108.3
       12             1
        5             4
        8             7
2         G4_MERCURIC_IODIDE       6.36     684.5
       80             1
       53             2
2                 G4_METHANE 0.000667151      41.7
        6             1
        1             4
3                 G4_METHANOL     0.7914      67.6
        6             1
        1             4
        8             1
5                G4_MIX_D_WAX       0.99      60.9
        1       0.13404
        6       0.77796
        8       0.03502
       12      0.038594
       22      0.014386
6               G4_MS20_TISSUE          1      75.1
        1      0.081192
        6      0.583442
        7      0.017798
        8      0.186381
       12      0.130287
       17        0.0009
9    G4_MUSCLE_SKELETAL_ICRP       1.05      75.3
        1         0.102
        6         0.143
        7         0.034
        8          0.71
       11         0.001
       15         0.002
       16         0.003
       17         0.001
       19         0.004
8    G4_MUSCLE_STRIATED_ICRU       1.04      74.7
        1      0.102102
        6      0.123123
        7      0.035035
        8       0.72973
       11      0.001001
       15      0.002002
       16      0.004004
       19      0.003003
4     G4_MUSCLE_WITH_SUCROSE       1.11      74.3
        1     0.0982341
        6      0.156214
        7      0.035451
        8      0.710101
4  G4_MUSCLE_WITHOUT_SUCROSE       1.07      74.2
        1      0.101969
        6      0.120058
        7      0.035451
        8      0.742522
2               G4_NAPHTHALENE      1.145      68.4
        6            10
        1             8
4             G4_NITROBENZENE    1.19867      75.8
        6             6
```

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```
        1             5
        7             1
        8             2
2           G4_NITROUS_OXIDE 0.00183094      84.9
        7             2
        8             1
4              G4_NYLON-8062       1.08      64.3
        1          0.103509
        6          0.648416
        7         0.0995361
        8          0.148539
4               G4_NYLON-6-6       1.14      63.9
        6             6
        1            11
        7             1
        8             1
4              G4_NYLON-6-10       1.14      63.2
        1          0.107062
        6          0.680449
        7          0.099189
        8            0.1133
4            G4_NYLON-11_RILSAN      1.425      61.6
        1          0.115476
        6          0.720818
        7         0.0764169
        8         0.0872889
2                 G4_OCTANE     0.7026      54.7
        6             8
        1            18
2                G4_PARAFFIN       0.93      55.9
        6            25
        1            52
2               G4_N-PENTANE     0.6262      53.6
        6             5
        1            12
8             G4_PHOTO_EMULSION      3.815       331
        1           0.0141
        6          0.072261
        7           0.01932
        8          0.066101
       16           0.00189
       35          0.349103
       47          0.474105
       53           0.00312
2 G4_PLASTIC_SC_VINYLTOLUENE      1.032      64.7
        6             9
        1            10
2         G4_PLUTONIUM_DIOXIDE      11.46     746.5
       94             1
        8             2
3         G4_POLYACRYLONITRILE       1.17      69.6
        6             3
        1             3
        7             1
3             G4_POLYCARBONATE        1.2      73.1
        6            16
        1            14
        8             3
3         G4_POLYCHLOROSTYRENE        1.3      81.7
        6             8
        1             7
       17             1
2              G4_POLYETHYLENE       0.94      57.4   (C_2H_4)_N-Polyethylene
        6             1
        1             2
3                    G4_MYLAR        1.4      78.7
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```
        6            10
        1             8
        8             4
3             G4_PLEXIGLASS       1.19        74
        6             5
        1             8
        8             2
3        G4_POLYOXYMETHYLENE      1.425      77.4
        6             1
        1             2
        8             1
2           G4_POLYPROPYLENE        0.9      56.5   (C_2H_4)_N-Polypropylene
        6             2
        1             4
2             G4_POLYSTYRENE       1.06      68.7
        6             8
        1             8
2                G4_TEFLON        2.2      99.1
        6             2
        9             4
3 G4_POLYTRIFLUOROCHLOROETHYLENE        2.1     120.7
        6             2
        9             3
       17             1
3       G4_POLYVINYL_ACETATE       1.19      73.7
        6             4
        1             6
        8             2
3       G4_POLYVINYL_ALCOHOL        1.3      69.7
        6             2
        1             4
        8             1
3       G4_POLYVINYL_BUTYRAL       1.12      67.2
        6             8
        1            14
        8             2
3      G4_POLYVINYL_CHLORIDE        1.3     108.2
        6             2
        1             3
       17             1
3 G4_POLYVINYLIDENE_CHLORIDE        1.7     134.3
        6             2
        1             2
       17             2
3 G4_POLYVINYLIDENE_FLUORIDE       1.76      88.8
        6             2
        1             2
        9             2
4   G4_POLYVINYL_PYRROLIDONE       1.25      67.7
        6             6
        1             9
        7             1
        8             1
2        G4_POTASSIUM_IODIDE       3.13     431.9
       19             1
       53             1
2         G4_POTASSIUM_OXIDE       2.32     189.9
       19             2
        8             1
2                G4_PROPANE 0.00187939      47.1
        6             3
        1             8
2               G4_lPROPANE       0.43        52
        6             3
        1             8
3        G4_N-PROPYL_ALCOHOL     0.8035      61.1
```

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```
        6             3
        1             8
        8             1
3               G4_PYRIDINE     0.9819      66.2
        6             5
        1             5
        7             1
2            G4_RUBBER_BUTYL       0.92      56.5
        1      0.143711
        6      0.856289
2          G4_RUBBER_NATURAL       0.92      59.8
        1      0.118371
        6      0.881629
3         G4_RUBBER_NEOPRENE       1.23        93
        1       0.05692
        6      0.542646
       17      0.400434
2         G4_SILICON_DIOXIDE       2.32     139.2   SiO_2
       14             1
        8             2
2          G4_SILVER_BROMIDE      6.473     486.6
       47             1
       35             1
2         G4_SILVER_CHLORIDE       5.56     398.4
       47             1
       17             1
3          G4_SILVER_HALIDES       6.47     487.1
       35      0.422895
       47      0.573748
       53      0.003357
2           G4_SILVER_IODIDE       6.01     543.5
       47             1
       53             1
9               G4_SKIN_ICRP       1.09      72.7
        1           0.1
        6         0.204
        7         0.042
        8         0.645
       11         0.002
       15         0.001
       16         0.002
       17         0.003
       19         0.001
3         G4_SODIUM_CARBONATE      2.532       125
       11             2
        6             1
        8             3
2           G4_SODIUM_IODIDE      3.667       452
       11             1
       53             1
2         G4_SODIUM_MONOXIDE       2.27     148.8
       11             2
        8             1
3          G4_SODIUM_NITRATE      2.261     114.6
       11             1
        7             1
        8             3
2               G4_STILBENE     0.9707      67.7
        6            14
        1            12
3                G4_SUCROSE     1.5805      77.5
        6            12
        1            22
        8            11
2               G4_TERPHENYL       1.24      71.7
        6            18
```

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```
        1            14
9            G4_TESTIS_ICRP       1.04        75
        1         0.106
        6         0.099
        7          0.02
        8         0.766
       11         0.002
       15         0.001
       16         0.002
       17         0.002
       19         0.002
2     G4_TETRACHLOROETHYLENE      1.625     159.2
        6             2
       17             4
2       G4_THALLIUM_CHLORIDE      7.004     690.3
       81             1
       17             1
9        G4_TISSUE_SOFT_ICRP       1.03      72.3
        1         0.105
        6         0.256
        7         0.027
        8         0.602
       11         0.001
       15         0.002
       16         0.003
       17         0.002
       19         0.002
4      G4_TISSUE_SOFT_ICRU-4          1      74.9
        1         0.101
        6         0.111
        7         0.026
        8         0.762
4          G4_TISSUE-METHANE 0.00106409      61.2
        1      0.101869
        6      0.456179
        7      0.035172
        8       0.40678
4          G4_TISSUE-PROPANE 0.00182628      59.5
        1      0.102672
        6       0.56894
        7      0.035022
        8      0.293366
2        G4_TITANIUM_DIOXIDE       4.26     179.5
       22             1
        8             2
2                G4_TOLUENE     0.8669      62.5
        6             7
        1             8
3       G4_TRICHLOROETHYLENE       1.46     148.1
        6             2
        1             1
       17             3
4      G4_TRIETHYL_PHOSPHATE       1.07      81.2
        6             6
        1            15
        8             4
       15             1
2   G4_TUNGSTEN_HEXAFLUORIDE        2.4     354.4
       74             1
        9             6
2       G4_URANIUM_DICARBIDE      11.28       752
       92             1
        6             2
2     G4_URANIUM_MONOCARBIDE      13.63       862
       92             1
        6             1
```

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```
 2           G4_URANIUM_OXIDE      10.96      720.6
        92             1
         8             2
 4                    G4_UREA      1.323       72.8
         6             1
         1             4
         7             2
         8             1
 4                   G4_VALINE       1.23       67.7
         6             5
         1            11
         7             1
         8             2
 3                    G4_VITON        1.8       98.6
         1      0.009417
         6      0.280555
         9      0.710028
 2                    G4_WATER          1         78   H_2O
         1             2
         8             1
 2             G4_WATER_VAPOR 0.000756182       71.6   H_2O-Gas
         1             2
         8             1
 2                   G4_XYLENE       0.87       61.8
         6             8
         1            10
 1                 G4_GRAPHITE       2.21         78   Graphite
```

11.6.3 HEP and Nuclear Materials

```
============================================================
 Ncomp              Name      density(g/cm^3)  I(eV) ChFormula
============================================================
 1                    G4_lH2     0.0708       21.8
 1                    G4_lN2      0.807         82
 1                    G4_lO2      1.141         95
 1                    G4_lAr      1.396        188
 1                    G4_lBr     3.1028        343
 1                    G4_lKr      2.418        352
 1                    G4_lXe      2.953        482
 3                   G4_PbWO4       8.28          0
         8             4
        82             1
        74             1
 1                 G4_Galactic      1e-25       21.8
 1          G4_GRAPHITE_POROUS        1.7         78   Graphite
 3                   G4_LUCITE       1.19         74
         1      0.080538
         6      0.599848
         8      0.319614
 3                    G4_BRASS       8.52          0
        29            62
        30            35
        82             3
 3                   G4_BRONZE       8.82          0
        29            89
        30             9
        82             2
 3          G4_STAINLESS-STEEL          8          0
        26            74
        24            18
        28             8
 3                    G4_CR39       1.32          0
```

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```
         1            18
         6            12
         8             7
 3            G4_OCTADECANOL      0.812         0
         1            38
         6            18
         8             1
```

11.6.4 Space (ISS) Materials

```
============================================================
 Ncomp             Name      density(g/cm^3)  I(eV) ChFormula
============================================================
 4                 G4_KEVLAR       1.44         0
         6            14
         1            10
         8             2
         7             2
 3                 G4_DACRON        1.4         0
         6            10
         1             8
         8             4
 3                G4_NEOPRENE       1.23         0
         6             4
         1             5
        17             1
```

11.6.5 Bio-Chemical Materials

```
============================================================
 Ncomp             Name      density(g/cm^3)  I(eV) ChFormula
============================================================
 4                G4_CYTOSINE       1.55        72
         1             5
         6             4
         7             3
         8             1
 4                 G4_THYMINE       1.23        72
         1             6
         6             5
         7             2
         8             2
 4                  G4_URACIL       1.32        72
         1             4
         6             4
         7             2
         8             2
 3             G4_DNA_ADENINE          1        72
         1             4
         6             5
         7             5
 4             G4_DNA_GUANINE          1        72
         1             4
         6             5
         7             5
         8             1
 4            G4_DNA_CYTOSINE          1        72
         1             4
         6             4
         7             3
```

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```
        8             1
4             G4_DNA_THYMINE          1        72
        1             5
        6             5
        7             2
        8             2
4              G4_DNA_URACIL          1        72
        1             3
        6             4
        7             2
        8             2
4           G4_DNA_ADENOSINE          1        72
        1            10
        6            10
        7             5
        8             4
4           G4_DNA_GUANOSINE          1        72
        1            10
        6            10
        7             5
        8             5
4            G4_DNA_CYTIDINE          1        72
        1            10
        6             9
        7             3
        8             5
4             G4_DNA_URIDINE          1        72
        1             9
        6             9
        7             2
        8             6
4       G4_DNA_METHYLURIDINE          1        72
        1            11
        6            10
        7             2
        8             6
2       G4_DNA_MONOPHOSPHATE          1        72
       15             1
        8             3
5                  G4_DNA_A          1        72
        1            10
        6            10
        7             5
        8             7
       15             1
5                  G4_DNA_G          1        72
        1            10
        6            10
        7             5
        8             8
       15             1
5                  G4_DNA_C          1        72
        1            10
        6             9
        7             3
        8             8
       15             1
5                  G4_DNA_U          1        72
        1             9
        6             9
        7             2
        8             9
       15             1
5                 G4_DNA_MU          1        72
        1            11
        6            10
```

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```
 7          2
 8          9
15          1
```

11.7 Transportation in Magnetic Field - Further Details

11.7.1 The challenge of integrating all tracks

What leads us to discard tracks looping in a magnetic field

The integration of charged particle tracks in magnetic field is an important part of the computational cost (CPU time). Part of this cost is due to integration of low-energy particles in a volume with low density and strong magnetic field.

In HEP applications the most important type of tracks causing such problems are electrons in the vacuum of beam pipes. Charged particles in volumes near decay volumes and muons in large volumes of air are other examples.

To limit this CPU cost, an effective tracking cut was implemented since Geant4 release 7.0 in `G4Transportation` and `G4CoupledTransportation`. Tracks which require more than a threshold number of integration steps (currently 1,000) during a physics/tracking step are marked as 'looping' and are considered candidates for being killed - i.e. they can potentially be abandoned after the current step, and have their energy deposited locally.

Recent enhancements (in 10.5-beta) have provided more comprehensive information about the tracks killed, in the form of G4Exceptions warning messages.

This section describes this policy, the parameters which the user is able to set to tune it, and recent refinements implemented in Geant4 10.5.

Cost of integration

Occasionally tracks 'looping' in a strong magnetic field, making little progress even over thousands of integration steps. This is due to a combination of a strong magnetic field and a thin material (gas or vacuum) in which the size of a physics step is substantially larger than the radius of curvature of the track.

The preferred integration method for tracks in an EM field is the Runge-Kutta method. This and other similar methods are well suited to variations in magnetic fields and step sizes up to a few times the radius of curvature of the charged tracks.

However when the step sizes are hundreds or thousands of times larger than the curvature of the track, these methods are expensive as they do not progress the integration of a track adequately.

The amount of CPU time which can be consumed by one or few such tracks can very large, sometimes contributing per cent increases to the simulation of some primary particles. Some tracks with a very small drift velocity (projection of the velocity along the vector of the magnetic field) can stop the progress of a simulation if they are not limited or integrated using alternative means.

So it is important to limit the number of integration steps spent on these tracks. The module for propagation in field in Geant4 flags tracks which take more than a certain number (default 1,000) integration steps without reaching the requested end of the step size, which was determined by the physics and geometry.

Parameters for eliminating or controling which particles are killed

The Geant4 `G4Transportation` and `G4CoupledTransportation` processes are tasked to select which of the tracks flagged as looping are killed and which survive. To balance the potential significant cost of integrating looping particles, three thresholds exist: - the 'Warning' Energy: a track with energy below this value that is found to loop is killed silently (no warning.) Above the 'Warning Energy', if a track is selected for killing then a warning is generated. - the 'Important' Energy: the threshold energy above which a track will survive for multiple steps if found looping. - the number of extra 'tracking' steps for important particles. These tracks will be only be killed only if they still

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