SE 4TE3
Continuous Optimization Algorithms
Radiation Therapy Optimization Project

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Chapter 1

Introduction

1.1 Prostate Cancer

Prostate cancer is the most common cancer that affect Canadian men. It is basically a disease where the prostate cell undergoes uncontrolled growth, abnormal structure, and the ability to move to other parts of the body, which essentially make it no longer function as a healthy cell. [3]

1.2 Prostate Cancer Radiation Therapy

The treatment planning for patients diagnosed with prostate cancer starts after the patient is diagnosed, then completes the necessary CT (Computed Tomography) scans, and then the tumour volume and radiosensitive or critical organs are mapped out. At this point the patient's specific radiotherapy treatment is planned, which is delivered daily over six to eight weeks.

1.3 Identifying the Clinical Target Volume

For the purpose of treatment planning, critical organs and the tumour volume are identified. The clinical target volume (CTV) is the tumour volume plus all the surrounding areas that might be at risk. Later the Planning Target Volume (PTV) is obtained and this would be the are exposed to the prescribed dose. Later we identify the organs at risk (OAR). These are the organs that might be in close proximity to the treatment volume. For prostate cancer, the OARs are the bladder, rectum and femoral heads as shown in figure 1.1. Based on this information the treatment planner could make the decision of which parts needs to be targeted and the accurate doses of radiation for the different areas. [4]

In an ideal scenario the radiation therapy treatment is done in way such the a high dose of radiation is sent out to the cancerous tissue and minimizing the dose of radiation on the healthy ones. Conventional radiation therapy treatments

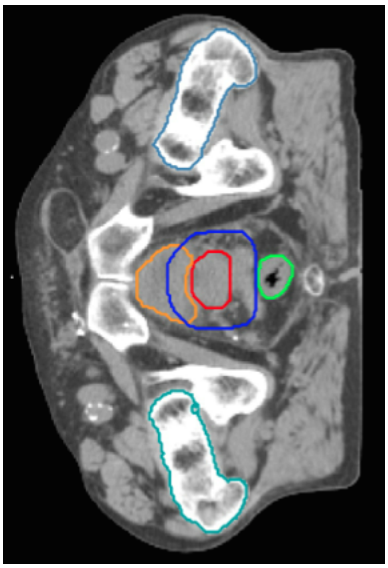

Figure 1.1: CT Slice representing the CTV, PTV, and OARs

take a trial and error approach by the radiation oncologists' supervision, which could be a very lengthy process or not necessarily the optimal solution.

1.4 Intensity-Modulated Radiation Therapy

In this document we will be dealing with Intensity-Modulated Radiation Therapy(IMRT). IMRT combines two techniques for the dose delivery, non-uniform intensity of the radiation beams, and inverse treatment planning via computerized optimization. [5] Basically, Modulating the intensity of radiation throughout the patient while delivering a highly-conformal dose of radiation to the target volume. This would help to better preserve normal tissues when compared to the conventional radiation therapy. Intensity Modulation is achieved by dividing the radiation beam into smaller beamlets that vary in intensities. The further it moves away from the tumour the radiation intensity decreases. By utilizing the different angles of delivery and the various beamlets would help to achieve the desired conformal dose distribution. [4]

1.5 Radiation Delivery

The radiation is delivered to the patient through a Linear Particle Accelerator (LINAC) equipped with a multi-leaf collimator (MLC). Multi-leaf collimators are suitable for IMRT delivery due to the existence of the tungsten leaves that are used to control the radiation going out of the lead box. Moreover, during

the treatment the LINAC's gantry rotate to shoot the radiation from different angles. The dosage builds up to the prescribed amount in PTV.

Chapter 2

Implementation

2.1 Method

The CT scan of patients body is divided into Voxels (Volume Pixels). The complete radiation beam is discretized into numerous beamlets. Each beamlet has an associated intensity and angle with respect to its neighbouring beamlet. This approach for IMRT follows the pencil beam algorithm. [2]

$$d_{i,j} = \sum_{\theta,t} D_{\theta,t,i,j} w_{\theta,t}$$

In the above equation $d_{i,j}$ represent the dose in a voxel i, j. Whereas, $\sum_{\theta,t} D_{\theta,t,i,j}$ represents the amount of the dose deposited per $w_{\theta,t}$. Also, $w_{\theta,t}$ is the unit weight of beamlet θ, t.

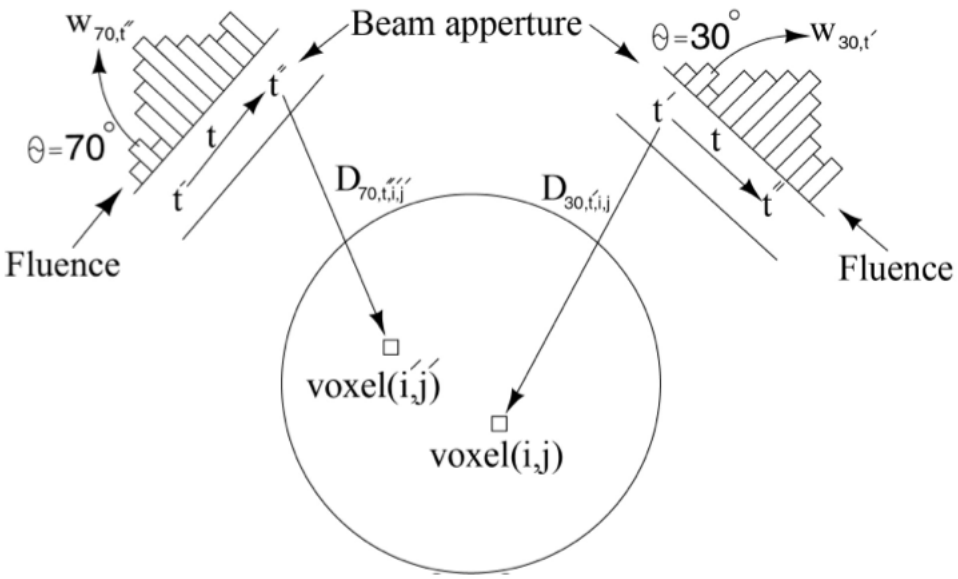

Figure 2.1: Fluence map beamlet and voxels in the discretized region of interest.

2.2 LP Formulation

The general form of a linear minimization problem is given by:

$$\begin{gathered} min\ c^T x \\ s.t\ Ax = b \\ x \geq 0 \end{gathered}$$

$c^T x$ is the cost of the function that shall be minimized.
$Ax = b$ is a constraint for the objective function
$x \geq 0$ is another constraint for the objective function being minimized.

As discussed, the variables for the problem are as follows:

- $w_{\theta,t}$ is the beamlet weight, proportional to photon fluence measured at a line of isocentre for a beam angle θ .
- t is the offset along the line.
- $d_{i,j}$ dose, the radiation dose delivered to voxel (i, j).
- $D_{\theta,t,i,j}$ finite size pencil beam dose distribution, represents the dose deposits in voxel i, j per unit weight of a beamlet θ, t.

- T is the set of voxels belonging to the PTV.
- R is the set of rectum voxels, with M_r maximum average dose.
- H is the set of femoral heads voxels, with M_h maximum average dose.
- B is the set of bladder voxels, with M_b maximum average dose.

Now, our optimization problem is defined as follows:

$$\begin{gathered} min \sum_{\theta,t} \tau_{\theta,t} \\ \text{s.t } w_{\theta,t} - w_{\theta,t+1} \leq \tau_{\theta,t}, \forall \theta, t \\ -w_{\theta,t} + w_{\theta,t+1} \leq \tau_{\theta,t}, \forall \theta, t \\ d_{i,j} = \sum_{\theta,t} D_{\theta,t,i,j} w_{\theta,t} \ \forall i, j \\ 0 \leq w_{\theta,t} \leq w_{max}, \forall \theta, t \\ w_{\theta,t_{max}} = 0, \forall \theta \\ w_{\theta,t_{min}} = 0, \forall \theta \\ 95 \leq d_{i,j} \leq 105, \forall i, j \in T \\ \sum_{i,j \in R} d_{i,j} \leq M_r |R| \\ \sum_{i,j \in H} d_{i,j} \leq M_h |H| \\ \sum_{i,j \in B} d_{i,j} \leq M_b |B| \end{gathered}$$

2.3 Karush-Kuhn-Tucker conditions

The Karush-Kuhn-Tucker (KKT) are first order conditions for a solution of nonlinear programming to be optimal, provided that some regularity conditions are satisfied.

General non-linear constrained minimum:

$$\begin{gathered} \text{min: } f(x) \\ \text{s.t: } h(x) = 0 \text{ (m equality constraints)} \\ g(x) \leq 0 \text{ (k inequality constraints)} \end{gathered}$$

Introduce slack variables s_i for the inequality constraints: $g_i(x) + s_i^2 == 0$ and construct the Lagrangian: $L(x, \lambda, \mu) = f(x) + \lambda h(x) + \sum \mu_i (g_i(x) + s_i^2)$

The gradient of the objective function must be perpendicular to the tangential plane of the constraints. That is the projection of the gradient f f onto the space of directions tangent to the constraints surface is zero.

The KKT conditions are as follows:

- Gradient of the Lagrangian $\lambda = 0$
- Constraints $h(x) = 0$ (m equality constraints) and $g(x) \leq 0$ (k inequality constraints)
- Complementary slackness (for the s_i variables) $\mu.s == 0$
- Feasibility for the inequality constraints $s_i^2 \geq 0$
- Sign condition on the inequality constraints: $\mu \geq 0$

2.4 Modelling Software

NEOS online server was our modelling software of choice. The reason we picked NEOS was due to the fact we test our optimization using the various solvers available on NEOS. For the purpose of this problem we used MOSEK. MOSEK is a well-know tool for solving mathematical problems such as linear programs, quadratic, conic problems and mixed integer problems. MOSEK was of great fit for the project because implements the interior-point method. [1]

2.5 AMPL Code

The code initially finds an optimal solution with no constraints set on neighbouring beamlets. This gives an optimal solution but would require many exposures which would be impractical in the real world due to the physical limitations of the hardware. In this solution, the 10, 50, 90, and 170 angles had 13, 15, 19, and 7 fluence steps, respectively.

The modified code looks at this original solution for each angle, and finds the pair of neighbouring beamlets with the smallest difference between them. A constraints is added to set this pair of beamlets to be equal, and the solver is run again. This process repeats until there are no neighbouring beamlets whose difference is less than the tolerance level.

We found that the problem became infeasible if run on the every angle at once, and decided to run it on angle 10 first. After it run, angle 10 went from 13 fluence steps, down to only 6, which is more much more feasible in the real world. This solution was taken, and the method was applied to angle 50. After running, it dropped from 15 down to 11. The process was repeated on angle 90, which went from 19 to 17 fluence steps. Finally, the process was run on angle 170 and the new solution was worse than the original, resulting in a jump from 7 to 13 fluence steps. The number of constraints on neighbouring beamlets, as well as the beamlets from other angles, resulted in decreasing returns in terms of fluence step minimization.

It is possible that applying the constraints to difference angles first might result in better results.

2.6 Input Reconstruction

Initially the input data was reconstructed using matplotlib (Python plotting). In the reconstruction, important organs were mapped and not the actual body shape. Also the dosage information from the constraints were identified in the plot's legend. The reconstruction can be seen in figure 2.2. The reconstruction was generated using the code referenced in Appendix B for generating the plots.

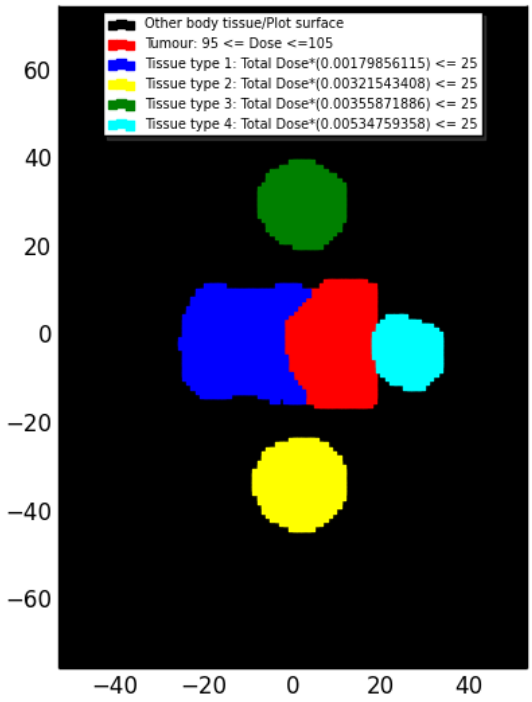

Figure 2.2: Input Data Reconstruction

2.7 Beamlet Exposure Intensties

In figure 2.3 it shows the calculated beam intensities for each angle. This was done using the code referenced in Appendix B for generating the plots.

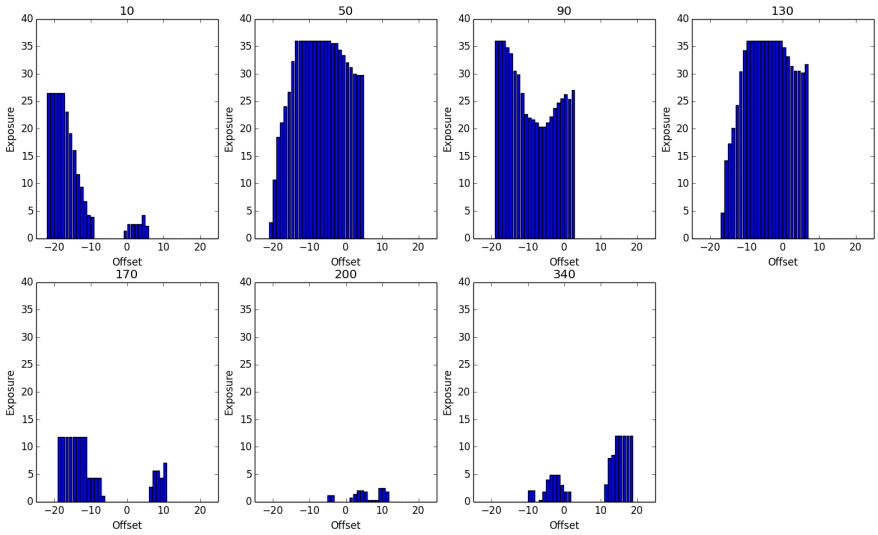

Figure 2.3: Beamlet Exposure Intensties

2.8 Heat Map

In figure 2.3 it shows the calculated dosage represented as a heat map. This was generated using the code referenced in Appendix B for generating the plots. Moreover, the image scale matched the reconstruction image scale.

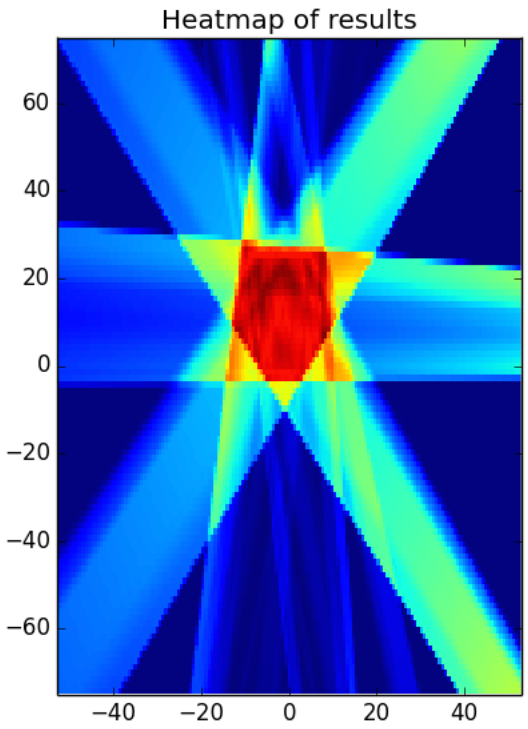

Figure 2.4: Heat Map/Dosage

2.9 Minimizing the varying exposure intensities

The solution was optimal, but not feasible in practice. The beamlet intensities varied which would take too much time to implement, and possibly causing potential patient distress. The goal was to minimize number of different exposure intensities. The solution was to iterate the optimization calculation. After each computation, set neighbouring beamlets to be the same intensity if difference is within a threshold. Represented in the figure 2.5 the solution after.

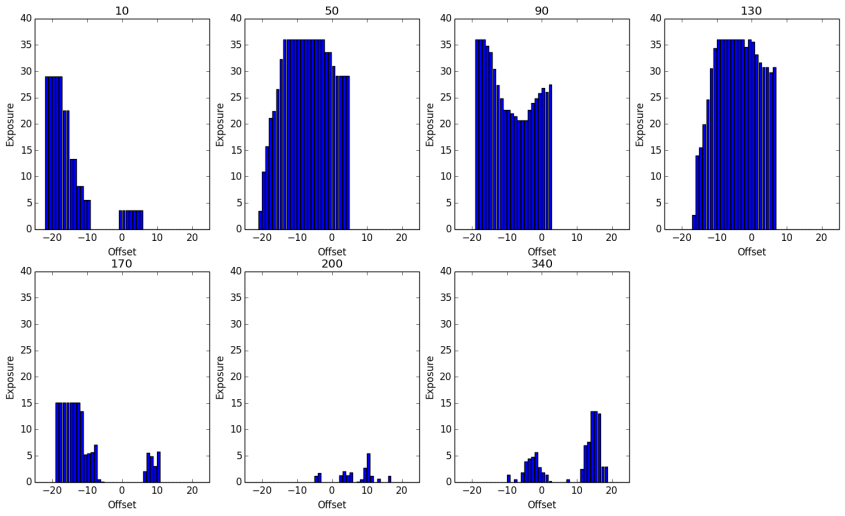

Figure 2.5: Beamlet Exposure Intensties - After

2.10 Improved Results

In figure **??** it shows the calculated dosage after the the varying intensities were minimized. This was generated using the code referenced in Appendix B for generating the plots.

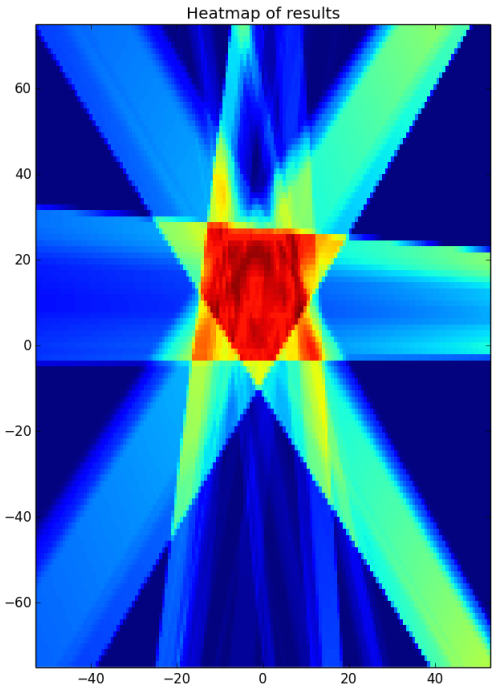

Figure 2.6: Heat Map/Dosage After

2.11 Future Work

Future work to our project could include the implementation of the simplex method. The simplex method would be very useful in our application in terms of minimizing the computation runs. In our problem when we first obtained the optimal solution we went through different iteration to further decrease the variation in beamlet intensities and essentially decreasing the number of exposures. The simplex method would have been beneficial in such scenario such that it deals with such problem given that we have a solution.

Moreover, this project could be further enhanced by making use of the various solvers offered by NEOS. In our runs we heavily depended on MOSEK. With our current implementation we fell in certain cases where NEOS returned infeasible solutions. Therefore, next iterations for this project shall include try outs with various solvers supported by NEOS.

Appendix A

AMPL Code

```
param pi := acos(-1);
param odm_radius_cm := 35;
param odm_per_cm := 4;
param dose_per_cm := 4;
param max_odm := odm_per_cm * odm_radius_cm*2;# to avoid error
param source_distance_cm := 100;
param n := 7;
set ANGLES := {10, 50, 90, 130, 170, 200, 340};

#-----------------------------------------

var difference := 100;
var tmp_offset := -25;
param tolerance := 3;
set constraint_set_10;
let constraint_set_10 := {};
set constraint_set_50;
let constraint_set_50 := {};
set constraint_set_90;
let constraint_set_90 := {};
set constraint_set_170;
let constraint_set_170 := {};
set constraint_check;

#-----------------------------------------

var rad{angle in ANGLES, offset in {-max_odm..max_odm}} >= 0;

param t{i in {-53..53},j in {-75..75}, angle in ANGLES} = (i/
    dose_per_cm*cos(angle*pi/180)+j/dose_per_cm*sin(angle*pi/180))
    /(i/dose_per_cm*cos(angle*pi/180)+j/dose_per_cm*sin(angle*pi
    /180)-source_distance_cm);
param s {i in{-53..53}, j in {-75..75}, angle in ANGLES} :=
    odm_per_cm * (-sin(angle*pi/180)*(i/dose_per_cm+t[i,j,angle]*(
    source_distance_cm*cos(angle*pi/180)-i/dose_per_cm)) +  cos(
    angle*pi/180)*(j/dose_per_cm+t[i,j,angle]*(source_distance_cm*
    sin(angle*pi/180)-j/dose_per_cm)));

```

```
param s_int {i in{-53..53}, j in {-75..75}, angle in ANGLES} := floor(s[i,j,angle]);
param s_frac {i in{-53..53}, j in {-75..75}, angle in ANGLES} := s[i,j,angle]- s_int[i,j,angle];
param s_frac1 {i in{-53..53}, j in {-75..75}, angle in ANGLES} := 1 - s_frac[i,j,angle];
var dose {i in {-53..53}, j in {-75..75}};

param geom {i in {-53..53}, j in {-75..75}, angle in ANGLES} := source_distance_cm*source_distance_cm/ (((source_distance_cm*cos(angle*pi/180)- i/dose_per_cm)^2)+
(source_distance_cm*sin(angle*pi/180)-j/dose_per_cm)^2);

var t2{angle in ANGLES, offset in {-max_odm+1..max_odm}} >= 0;

subject to constT12 {angle in ANGLES, offset in{-max_odm+1..max_odm}}:
        t2[angle,offset] >= rad[angle,offset] - rad[angle,offset-1];
subject to constT21 {angle in ANGLES, offset in {-max_odm+1..max_odm}}:
        -t2[angle,offset] <= rad[angle,offset] - rad[angle,offset-1];

#-----------------------------------------------------------

subject to test{i in {ANGLES}, j in{-max_odm..max_odm}}: rad[i,j] <= 36;


subject to const3 {i in {-53..53}, j in {-75..75}}:
 dose[i,j] =sum {angle in ANGLES}geom[i,j,angle]*((s_frac1[i,j,angle])*rad[angle,s_int[i,j,angle]]+(s_frac[i,j,angle])*rad[angle,1+s_int[i, j, angle]]);

# ----------------------------------------------------------------------------------
subject to const_68 {(i,j) in {(-2,-4),(-2,-3),(-2,-2),(-2,-1),(-2,0),(-2,1),(-2,2),(-2,3),(-2,4),
 (-1,-8),(-1,-7),(-1,-6),(-1,-5),(-1,-4),(-1,-3),(-1,-2),(-1,-1),(-1,0),(-1,1),(-1,2),(-1,3),(-1,4),
 (-1,5),(0,-10),(0,-9),(0,-8),(0,-7),(0,-6),(0,-5),(0,-4),(0,-3),(0,-2),(0,-1),(0,0),(0,1),(0,2),
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 (2,-6),(2,-5),(2,-4),(2,-3),(2,-2),(2,-1),(2,0),(2,1),(2,2),(2,3),(2,4),(2,5),(2,6),(2,7),(2,8),
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 (4,-10),(4,-9),(4,-8),(4,-7),(4,-6),(4,-5),(4,-4),(4,-3),(4,-2),(4,-1),(4,0),(4,1),(4,2),(4,3),
```

```
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       ,(5,-11),(5,-10),(5,-9),(5,-8),
66 (5,-7),(5,-6),(5,-5),(5,-4),(5,-3),(5,-2),(5,-1),(5,0),(5,1),(5,2)
       ,(5,3),(5,4),(5,5),(5,6),(5,7),
67 (5,8),(5,9),(5,10),(6,-15),(6,-14),(6,-13),(6,-12),(6,-11),(6,-10)
       ,(6,-9),(6,-8),(6,-7),(6,-6),
68 (6,-5),(6,-4),(6,-3),(6,-2),(6,-1),(6,0),(6,1),(6,2),(6,3),(6,4)
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69 (6,10),(7,-15),(7,-14),(7,-13),(7,-12),(7,-11),(7,-10),(7,-9)
       ,(7,-8),(7,-7),(7,-6),(7,-5),(7,-4),
70 (7,-3),(7,-2),(7,-1),(7,0),(7,1),(7,2),(7,3),(7,4),(7,5),(7,6)
       ,(7,7),(7,8),(7,9),(7,10),(7,11),
71 (8,-15),(8,-14),(8,-13),(8,-12),(8,-11),(8,-10),(8,-9),(8,-8)
       ,(8,-7),(8,-6),(8,-5),(8,-4),(8,-3),
72 (8,-2),(8,-1),(8,0),(8,1),(8,2),(8,3),(8,4),(8,5),(8,6),(8,7)
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73 (9,-15),(9,-14),(9,-13),(9,-12),(9,-11),(9,-10),(9,-9),(9,-8)
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74 (9,-2),(9,-1),(9,0),(9,1),(9,2),(9,3),(9,4),(9,5),(9,6),(9,7)
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76 (10,-4),(10,-3),(10,-2),(10,-1),(10,0),(10,1),(10,2),(10,3),(10,4)
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       ,(11,-11),(11,-10),(11,-9),
78 (11,-8),(11,-7),(11,-6),(11,-5),(11,-4),(11,-3),(11,-2),(11,-1)
       ,(11,0),(11,1),(11,2),(11,3),
79 (11,4),(11,5),(11,6),(11,7),(11,8),(11,9),(11,10),(11,11),(11,12)
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       ,(12,-4),(12,-3),(12,-2),
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       ,(13,-9),(13,-8),(13,-7),(13,-6),
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       ,(14,-12),(14,-11),(14,-10),
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       ,(14,-1),(14,0),(14,1),(14,2),
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       ,(14,12),(15,-15),(15,-14),
87 (15,-13),(15,-12),(15,-11),(15,-10),(15,-9),(15,-8),(15,-7)
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       ,(15,7),(15,8),(15,9),(15,10),
89 (15,11),(15,12),(16,-15),(16,-14),(16,-13),(16,-12),(16,-11)
       ,(16,-10),(16,-9),(16,-8),(16,-7),
90 (16,-6),(16,-5),(16,-4),(16,-3),(16,-2),(16,-1),(16,0),(16,1)
       ,(16,2),(16,3),(16,4),(16,5),
91 (16,6),(16,7),(16,8),(16,9),(16,10),(16,11),(16,12),(17,-15)
       ,(17,-14),(17,-13),(17,-12),
92 (17,-11),(17,-10),(17,-9),(17,-8),(17,-7),(17,-6),(17,-5),(17,-4)
       ,(17,-3),(17,-2),(17,-1),
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93  (17,0),(17,1),(17,2),(17,3),(17,4),(17,5),(17,6),(17,7),(17,8)
        ,(17,9),(17,10),(17,11),(18,-14),
94  (18,-13),(18,-12),(18,-11),(18,-10),(18,-9),(18,-8),(18,-7)
        ,(18,-6),(18,-5),(18,-4),(18,-3),
95  (18,-2),(18,-1),(18,0),(18,1),(18,2),(18,3),(18,4),(18,5),(18,6)
        ,(18,7),(18,8),(18,9),(18,10),
96  (18,11)}}: dose[i,j] >= 95;
97
98  subject to const1_68 {(i,j) in {(-2,-4),(-2,-3),(-2,-2),(-2,-1)
        ,(-2,0),(-2,1),(-2,2),(-2,3),
99  (-2,4),(-1,-8),(-1,-7),(-1,-6),(-1,-5),(-1,-4),(-1,-3),(-1,-2)
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108 (5,-10),(5,-9),(5,-8),(5,-7),(5,-6),(5,-5),(5,-4),(5,-3),(5,-2)
        ,(5,-1),(5,0),(5,1),(5,2),(5,3),(5,4)
109 ,(5,5),(5,6),(5,7),(5,8),(5,9),(5,10),(6,-15),(6,-14),(6,-13)
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111 (6,10),(7,-15),(7,-14),(7,-13),(7,-12),(7,-11),(7,-10),(7,-9)
        ,(7,-8),(7,-7),(7,-6),(7,-5),(7,-4),(7,-3),
112 (7,-2),(7,-1),(7,0),(7,1),(7,2),(7,3),(7,4),(7,5),(7,6),(7,7)
        ,(7,8),(7,9),(7,10),(7,11),(8,-15),(8,-14),
113 (8,-13),(8,-12),(8,-11),(8,-10),(8,-9),(8,-8),(8,-7),(8,-6),(8,-5)
        ,(8,-4),(8,-3),(8,-2),(8,-1),(8,0),
114 (8,1),(8,2),(8,3),(8,4),(8,5),(8,6),(8,7),(8,8),(8,9),(8,10)
        ,(8,11),(8,12),(9,-15),(9,-14),(9,-13),
115 (9,-12),(9,-11),(9,-10),(9,-9),(9,-8),(9,-7),(9,-6),(9,-5),(9,-4)
        ,(9,-3),(9,-2),(9,-1),(9,0),(9,1),
116 (9,2),(9,3),(9,4),(9,5),(9,6),(9,7),(9,8),(9,9),(9,10),(9,11)
        ,(9,12),(10,-15),(10,-14),(10,-13),(10,-12),
117 (10,-11),(10,-10),(10,-9),(10,-8),(10,-7),(10,-6),(10,-5),(10,-4)
        ,(10,-3),(10,-2),(10,-1),(10,0),(10,1),
118 (10,2),(10,3),(10,4),(10,5),(10,6),(10,7),(10,8),(10,9),(10,10)
        ,(10,11),(10,12),(11,-15),(11,-14),(11,-13),
119 (11,-12),(11,-11),(11,-10),(11,-9),(11,-8),(11,-7),(11,-6),(11,-5)
        ,(11,-4),(11,-3),(11,-2),(11,-1),(11,0),
120 (11,1),(11,2),(11,3),(11,4),(11,5),(11,6),(11,7),(11,8),(11,9)
        ,(11,10),(11,11),(11,12),(12,-15),(12,-14),
121 (12,-13),(12,-12),(12,-11),(12,-10),(12,-9),(12,-8),(12,-7)
        ,(12,-6),(12,-5),(12,-4),(12,-3),(12,-2),(12,-1),
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(12,0),(12,1),(12,2),(12,3),(12,4),(12,5),(12,6),(12,7),(12,8),(12,9),(12,10),(12,11),(12,12),(13,-15),
(13,-14),(13,-13),(13,-12),(13,-11),(13,-10),(13,-9),(13,-8),(13,-7),(13,-6),(13,-5),(13,-4),(13,-3),
(13,-2),(13,-1),(13,0),(13,1),(13,2),(13,3),(13,4),(13,5),(13,6),(13,7),(13,8),(13,9),(13,10),(13,11),
(13,12),(14,-15),(14,-14),(14,-13),(14,-12),(14,-11),(14,-10),(14,-9),(14,-8),(14,-7),(14,-6),(14,-5),
(14,-4),(14,-3),(14,-2),(14,-1),(14,0),(14,1),(14,2),(14,3),(14,4),(14,5),(14,6),(14,7),(14,8),(14,9),
(14,10),(14,11),(14,12),(15,-15),(15,-14),(15,-13),(15,-12),(15,-11),(15,-10),(15,-9),(15,-8),(15,-7),
(15,-6),(15,-5),(15,-4),(15,-3),(15,-2),(15,-1),(15,0),(15,1),(15,2),(15,3),(15,4),(15,5),(15,6),(15,7),
(15,8),(15,9),(15,10),(15,11),(15,12),(16,-15),(16,-14),(16,-13),(16,-12),(16,-11),(16,-10),(16,-9),
(16,-8),(16,-7),(16,-6),(16,-5),(16,-4),(16,-3),(16,-2),(16,-1),(16,0),(16,1),(16,2),(16,3),(16,4),
(16,5),(16,6),(16,7),(16,8),(16,9),(16,10),(16,11),(16,12),(17,-15),(17,-14),(17,-13),(17,-12),(17,-11),
(17,-10),(17,-9),(17,-8),(17,-7),(17,-6),(17,-5),(17,-4),(17,-3),(17,-2),(17,-1),(17,0),(17,1),(17,2),
(17,3),(17,4),(17,5),(17,6),(17,7),(17,8),(17,9),(17,10),(17,11),(18,-14),(18,-13),(18,-12),(18,-11),
(18,-10),(18,-9),(18,-8),(18,-7),(18,-6),(18,-5),(18,-4),(18,-3),(18,-2),(18,-1),(18,0),(18,1),(18,2),
(18,3),(18,4),(18,5),(18,6),(18,7),(18,8),(18,9),(18,10),
(18,11)}}: dose[i,j] <= 105;

# ----------------------------------------------------------------------------------------

param max_s := 25;

subject to const_2:(sum {(i,j) in {(-25,-2),(-25,-1),(-24,-9),(-24,-8),(-24,-7),(-24,-6),(-24,-5),(-24,-4),
(-24,-3),(-24,-2),(-24,-1),(-24,0),(-24,1),(-24,2),(-24,3),(-24,4),(-23,-10),(-23,-9),(-23,-8),(-23,-7),
(-23,-6),(-23,-5),(-23,-4),(-23,-3),(-23,-2),(-23,-1),(-23,0),(-23,1),(-23,2),(-23,3),(-23,4),(-23,5),
(-23,6),(-22,-11),(-22,-10),(-22,-9),(-22,-8),(-22,-7),(-22,-6),(-22,-5),(-22,-4),(-22,-3),(-22,-2),
(-22,-1),(-22,0),(-22,1),(-22,2),(-22,3),(-22,4),(-22,5),(-22,6),(-22,7),(-22,8),(-21,-12),(-21,-11),
(-21,-10),(-21,-9),(-21,-8),(-21,-7),(-21,-6),(-21,-5),(-21,-4),(-21,-3),(-21,-2),(-21,-1),(-21,0),
(-21,1),(-21,2),(-21,3),(-21,4),(-21,5),(-21,6),(-21,7),(-21,8),(-21,9),(-21,10),(-20,-13),(-20,-12),
(-20,-11),(-20,-10),(-20,-9),(-20,-8),(-20,-7),(-20,-6),(-20,-5),(-20,-4),(-20,-3),(-20,-2),(-20,-1),
(-20,0),(-20,1),(-20,2),(-20,3),(-20,4),(-20,5),(-20,6),(-20,7),(-20,8),(-20,9),(-20,10),(-19,-13),
(-19,-12),(-19,-11),(-19,-10),(-19,-9),(-19,-8),(-19,-7),(-19,-6),(-19,-5),(-19,-4),(-19,-3),(-19,-2),
(-19,-1),(-19,0),(-19,1),(-19,2),(-19,3),(-19,4),(-19,5),(-19,6),(-19,7),(-19,8),(-19,9),(-19,10),
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```
152 (-19,11),(-18,-13),(-18,-12),(-18,-11),(-18,-10),(-18,-9),(-18,-8)
        ,(-18,-7),(-18,-6),(-18,-5),(-18,-4),
153 (-18,-3),(-18,-2),(-18,-1),(-18,0),(-18,1),(-18,2),(-18,3),(-18,4)
        ,(-18,5),(-18,6),(-18,7),(-18,8),
154 (-18,9),(-18,10),(-18,11),(-17,-13),(-17,-12),(-17,-11),(-17,-10)
        ,(-17,-9),(-17,-8),(-17,-7),(-17,-6),
155 (-17,-5),(-17,-4),(-17,-3),(-17,-2),(-17,-1),(-17,0),(-17,1)
        ,(-17,2),(-17,3),(-17,4),(-17,5),(-17,6),
156 (-17,7),(-17,8),(-17,9),(-17,10),(-17,11),(-16,-13),(-16,-12)
        ,(-16,-11),(-16,-10),(-16,-9),(-16,-8),
157 (-16,-7),(-16,-6),(-16,-5),(-16,-4),(-16,-3),(-16,-2),(-16,-1)
        ,(-16,0),(-16,1),(-16,2),(-16,3),(-16,4),
158 (-16,5),(-16,6),(-16,7),(-16,8),(-16,9),(-16,10),(-16,11)
        ,(-15,-13),(-15,-12),(-15,-11),(-15,-10),
159 (-15,-9),(-15,-8),(-15,-7),(-15,-6),(-15,-5),(-15,-4),(-15,-3)
        ,(-15,-2),(-15,-1),(-15,0),(-15,1),(-15,2),
160 (-15,3),(-15,4),(-15,5),(-15,6),(-15,7),(-15,8),(-15,9),(-15,10)
        ,(-14,-12),(-14,-11),(-14,-10),(-14,-9),
161 (-14,-8),(-14,-7),(-14,-6),(-14,-5),(-14,-4),(-14,-3),(-14,-2)
        ,(-14,-1),(-14,0),(-14,1),(-14,2),(-14,3),
162 (-14,4),(-14,5),(-14,6),(-14,7),(-14,8),(-14,9),(-14,10),(-13,-12)
        ,(-13,-11),(-13,-10),(-13,-9),(-13,-8),
163 (-13,-7),(-13,-6),(-13,-5),(-13,-4),(-13,-3),(-13,-2),(-13,-1)
        ,(-13,0),(-13,1),(-13,2),(-13,3),(-13,4),
164 (-13,5),(-13,6),(-13,7),(-13,8),(-13,9),(-13,10),(-12,-12)
        ,(-12,-11),
165 (-12,-10),(-12,-9),(-12,-8),(-12,-7),(-12,-6),(-12,-5),(-12,-4)
        ,(-12,-3),(-12,-2),(-12,-1),(-12,0),
166 (-12,1),(-12,2),(-12,3),(-12,4),(-12,5),(-12,6),(-12,7),(-12,8)
        ,(-12,9),(-12,10),(-11,-12),(-11,-11),
167 (-11,-10),(-11,-9),(-11,-8),(-11,-7),(-11,-6),(-11,-5),(-11,-4)
        ,(-11,-3),(-11,-2),(-11,-1),(-11,0),
168 (-11,1),(-11,2),(-11,3),(-11,4),(-11,5),(-11,6),(-11,7),(-11,8)
        ,(-11,9),(-11,10),(-10,-12),(-10,-11),
169 (-10,-10),(-10,-9),(-10,-8),(-10,-7),(-10,-6),(-10,-5),(-10,-4)
        ,(-10,-3),(-10,-2),(-10,-1),(-10,0),
170 (-10,1),(-10,2),(-10,3),(-10,4),(-10,5),(-10,6),(-10,7),(-10,8)
        ,(-10,9),(-10,10),(-9,-12),(-9,-11),
171 (-9,-10),(-9,-9),(-9,-8),(-9,-7),(-9,-6),(-9,-5),(-9,-4),(-9,-3)
        ,(-9,-2),(-9,-1),(-9,0),(-9,1),(-9,2),
172 (-9,3),(-9,4),(-9,5),(-9,6),(-9,7),(-9,8),(-9,9),(-9,10),(-8,-12)
        ,(-8,-11),(-8,-10),(-8,-9),(-8,-8),
173 (-8,-7),(-8,-6),(-8,-5),(-8,-4),(-8,-3),(-8,-2),(-8,-1),(-8,0)
        ,(-8,1),(-8,2),(-8,3),(-8,4),(-8,5),
174 (-8,6),(-8,7),(-8,8),(-8,9),(-8,10),(-7,-13),(-7,-12),(-7,-11)
        ,(-7,-10),(-7,-9),(-7,-8),(-7,-7),
175 (-7,-6),(-7,-5),(-7,-4),(-7,-3),(-7,-2),(-7,-1),(-7,0),(-7,1)
        ,(-7,2),(-7,3),(-7,4),(-7,5),(-7,6),
176 (-7,7),(-7,8),(-7,9),(-7,10),(-6,-13),(-6,-12),(-6,-11),(-6,-10)
        ,(-6,-9),(-6,-8),(-6,-7),(-6,-6),
177 (-6,-5),(-6,-4),(-6,-3),(-6,-2),(-6,-1),(-6,0),(-6,1),(-6,2)
        ,(-6,3),(-6,4),(-6,5),(-6,6),(-6,7),
178 (-6,8),(-6,9),(-6,10),(-5,-13),(-5,-12),(-5,-11),(-5,-10),(-5,-9)
        ,(-5,-8),(-5,-7),(-5,-6),(-5,-5),
179 (-5,-4),(-5,-3),(-5,-2),(-5,-1),(-5,0),(-5,1),(-5,2),(-5,3),(-5,4)
        ,(-5,5),(-5,6),(-5,7),(-5,8),
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180  (-5,9),(-5,10),(-4,-14),(-4,-13),(-4,-12),(-4,-11),(-4,-10)
         ,(-4,-9),(-4,-8),(-4,-7),(-4,-6),(-4,-5),
181  (-4,-4),(-4,-3),(-4,-2),(-4,-1),(-4,0),(-4,1),(-4,2),(-4,3),(-4,4)
         ,(-4,5),(-4,6),(-4,7),(-4,8),(-4,9),
182  (-4,10),(-3,-13),(-3,-12),(-3,-11),(-3,-10),(-3,-9),(-3,-8)
         ,(-3,-7),(-3,-6),(-3,-5),(-3,-4),(-3,-3),
183  (-3,-2),(-3,-1),(-3,0),(-3,1),(-3,2),(-3,3),(-3,4),(-3,5),(-3,6)
         ,(-3,7),(-3,8),(-3,9),(-3,10),(-3,11),
184  (-2,-13),(-2,-12),(-2,-11),(-2,-10),(-2,-9),(-2,-8),(-2,-7)
         ,(-2,-6),(-2,-5),(-2,5),(-2,6),(-2,7),(-2,8),
185  (-2,9),(-2,10),(-2,11),(-1,-14),(-1,-13),(-1,-12),(-1,-11)
         ,(-1,-10),(-1,-9),(-1,6),(-1,7),(-1,8),(-1,9),
186  (-1,10),(-1,11),(0,-14),(0,-13),(0,-12),(0,-11),(0,7),(0,8),(0,9)
         ,(0,10),(0,11),(1,-14),(1,-13),(1,-12),
187  (1,8),(1,9),(1,10),(1,11),(2,-14),(2,-13),(2,9),(2,10),(3,10)
188  }}dose[i,j])*(0.00179856115) <= max_s;
189
190
191 subject to const_3:(sum {(i,j) in {(-8,-35),(-8,-34),(-8,-33)
         ,(-8,-32),(-8,-31),(-7,-37),(-7,-36),
192  (-7,-35),(-7,-34),(-7,-33),(-7,-32),(-7,-31),(-7,-30),(-7,-29)
         ,(-6,-39),(-6,-38),(-6,-37),
193  (-6,-36),(-6,-35),(-6,-34),(-6,-33),(-6,-32),(-6,-31),(-6,-30)
         ,(-6,-29),(-6,-28),(-6,-27),
194  (-5,-40),(-5,-39),(-5,-38),(-5,-37),(-5,-36),(-5,-35),(-5,-34)
         ,(-5,-33),(-5,-32),(-5,-31),
195  (-5,-30),(-5,-29),(-5,-28),(-5,-27),(-5,-26),(-4,-41),(-4,-40)
         ,(-4,-39),(-4,-38),(-4,-37),
196  (-4,-36),(-4,-35),(-4,-34),(-4,-33),(-4,-32),(-4,-31),(-4,-30)
         ,(-4,-29),(-4,-28),(-4,-27),
197  (-4,-26),(-3,-41),(-3,-40),(-3,-39),(-3,-38),(-3,-37),(-3,-36)
         ,(-3,-35),(-3,-34),(-3,-33),
198  (-3,-32),(-3,-31),(-3,-30),(-3,-29),(-3,-28),(-3,-27),(-3,-26)
         ,(-3,-25),(-2,-42),(-2,-41),
199  (-2,-40),(-2,-39),(-2,-38),(-2,-37),(-2,-36),(-2,-35),(-2,-34)
         ,(-2,-33),(-2,-32),(-2,-31),
200  (-2,-30),(-2,-29),(-2,-28),(-2,-27),(-2,-26),(-2,-25),(-1,-42)
         ,(-1,-41),(-1,-40),(-1,-39),
201  (-1,-38),(-1,-37),(-1,-36),(-1,-35),(-1,-34),(-1,-33),(-1,-32)
         ,(-1,-31),(-1,-30),(-1,-29),
202  (-1,-28),(-1,-27),(-1,-26),(-1,-25),(0,-43),(0,-42),(0,-41)
         ,(0,-40),(0,-39),(0,-38),(0,-37),
203  (0,-36),(0,-35),(0,-34),(0,-33),(0,-32),(0,-31),(0,-30),(0,-29)
         ,(0,-28),(0,-27),(0,-26),
204  (0,-25),(0,-24),(1,-43),(1,-42),(1,-41),(1,-40),(1,-39),(1,-38)
         ,(1,-37),(1,-36),(1,-35),
205  (1,-34),(1,-33),(1,-32),(1,-31),(1,-30),(1,-29),(1,-28),(1,-27)
         ,(1,-26),(1,-25),(1,-24),
206  (2,-43),(2,-42),(2,-41),(2,-40),(2,-39),(2,-38),(2,-37),(2,-36)
         ,(2,-35),(2,-34),(2,-33),
207  (2,-32),(2,-31),(2,-30),(2,-29),(2,-28),(2,-27),(2,-26),(2,-25)
         ,(2,-24),(3,-43),(3,-42),
208  (3,-41),(3,-40),(3,-39),(3,-38),(3,-37),(3,-36),(3,-35),(3,-34)
         ,(3,-33),(3,-32),(3,-31),
209  (3,-30),(3,-29),(3,-28),(3,-27),(3,-26),(3,-25),(3,-24),(4,-43)
         ,(4,-42),(4,-41),(4,-40),
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210  (4,-39),(4,-38),(4,-37),(4,-36),(4,-35),(4,-34),(4,-33),(4,-32)
         ,(4,-31),(4,-30),(4,-29),
211  (4,-28),(4,-27),(4,-26),(4,-25),(4,-24),(5,-42),(5,-41),(5,-40)
         ,(5,-39),(5,-38),(5,-37),
212  (5,-36),(5,-35),(5,-34),(5,-33),(5,-32),(5,-31),(5,-30),(5,-29)
         ,(5,-28),(5,-27),(5,-26),
213  (5,-25),(5,-24),(6,-42),(6,-41),(6,-40),(6,-39),(6,-38),(6,-37)
         ,(6,-36),(6,-35),(6,-34),
214  (6,-33),(6,-32),(6,-31),(6,-30),(6,-29),(6,-28),(6,-27),(6,-26)
         ,(6,-25),(7,-41),(7,-40),
215  (7,-39),(7,-38),(7,-37),(7,-36),(7,-35),(7,-34),(7,-33),(7,-32)
         ,(7,-31),(7,-30),(7,-29),
216  (7,-28),(7,-27),(7,-26),(7,-25),(8,-40),(8,-39),(8,-38),(8,-37)
         ,(8,-36),(8,-35),(8,-34),
217  (8,-33),(8,-32),(8,-31),(8,-30),(8,-29),(8,-28),(8,-27),(8,-26)
         ,(9,-39),(9,-38),(9,-37),
218  (9,-36),(9,-35),(9,-34),(9,-33),(9,-32),(9,-31),(9,-30),(9,-29)
         ,(9,-28),(9,-27),(10,-38),
219  (10,-37),(10,-36),(10,-35),(10,-34),(10,-33),(10,-32),(10,-31)
         ,(10,-30),(10,-29),(10,-28),
220  (11,-36),(11,-35),(11,-34),(11,-33),(11,-32),(11,-31),(11,-30)
221 }} dose[i,j])*(0.00321543408) <= max_s;
222
223 subject to const_4:(sum {(i,j) in {(-7,28),(-7,29),(-7,30),(-7,31)
         ,(-7,32),(-7,33),(-6,27),(-6,28),
224  (-6,29),(-6,30),(-6,31),(-6,32),(-6,33),(-6,34),(-5,25),(-5,26)
         ,(-5,27),(-5,28),(-5,29),
225  (-5,30),(-5,31),(-5,32),(-5,33),(-5,34),(-5,35),(-5,36),(-4,24)
         ,(-4,25),(-4,26),(-4,27),
226  (-4,28),(-4,29),(-4,30),(-4,31),(-4,32),(-4,33),(-4,34),(-4,35)
         ,(-4,36),(-4,37),(-3,23),
227  (-3,24),(-3,25),(-3,26),(-3,27),(-3,28),(-3,29),(-3,30),(-3,31)
         ,(-3,32),(-3,33),(-3,34),
228  (-3,35),(-3,36),(-3,37),(-2,22),(-2,23),(-2,24),(-2,25),(-2,26)
         ,(-2,27),(-2,28),(-2,29),
229  (-2,30),(-2,31),(-2,32),(-2,33),(-2,34),(-2,35),(-2,36),(-2,37)
         ,(-2,38),(-1,22),(-1,23),
230  (-1,24),(-1,25),(-1,26),(-1,27),(-1,28),(-1,29),(-1,30),(-1,31)
         ,(-1,32),(-1,33),(-1,34),
231  (-1,35),(-1,36),(-1,37),(-1,38),(0,22),(0,23),(0,24),(0,25),(0,26)
         ,(0,27),(0,28),(0,29),
232  (0,30),(0,31),(0,32),(0,33),(0,34),(0,35),(0,36),(0,37),(0,38)
         ,(0,39),(1,21),(1,22),(1,23),
233  (1,24),(1,25),(1,26),(1,27),(1,28),(1,29),(1,30),(1,31),(1,32)
         ,(1,33),(1,34),(1,35),(1,36),
234  (1,37),(1,38),(1,39),(2,21),(2,22),(2,23),(2,24),(2,25),(2,26)
         ,(2,27),(2,28),(2,29),(2,30),
235  (2,31),(2,32),(2,33),(2,34),(2,35),(2,36),(2,37),(2,38),(2,39)
         ,(3,21),(3,22),(3,23),(3,24),
236  (3,25),(3,26),(3,27),(3,28),(3,29),(3,30),(3,31),(3,32),(3,33)
         ,(3,34),(3,35),(3,36),(3,37),
237  (3,38),(3,39),(4,21),(4,22),(4,23),(4,24),(4,25),(4,26),(4,27)
         ,(4,28),(4,29),(4,30),(4,31),
238  (4,32),(4,33),(4,34),(4,35),(4,36),(4,37),(4,38),(4,39),(5,21)
         ,(5,22),(5,23),(5,24),(5,25),
239  (5,26),(5,27),(5,28),(5,29),(5,30),(5,31),(5,32),(5,33),(5,34)
         ,(5,35),(5,36),(5,37),(5,38),
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240   (6,21),(6,22),(6,23),(6,24),(6,25),(6,26),(6,27),(6,28),(6,29)
          ,(6,30),(6,31),(6,32),(6,33),
241   (6,34),(6,35),(6,36),(6,37),(6,38),(7,22),(7,23),(7,24),(7,25)
          ,(7,26),(7,27),(7,28),(7,29),
242   (7,30),(7,31),(7,32),(7,33),(7,34),(7,35),(7,36),(7,37),(8,23)
          ,(8,24),(8,25),(8,26),(8,27),
243   (8,28),(8,29),(8,30),(8,31),(8,32),(8,33),(8,34),(8,35),(8,36)
          ,(9,24),(9,25),(9,26),(9,27),
244   (9,28),(9,29),(9,30),(9,31),(9,32),(9,33),(9,34),(9,35),(9,36)
          ,(10,25),(10,26),(10,27),
245   (10,28),(10,29),(10,30),(10,31),(10,32),(10,33),(10,34),(10,35)
          ,(11,27),(11,28),(11,29),
246   (11,30),(11,31),(11,32),(11,33),(11,34)}}
247   dose[i,j])*(0.00355871886) <= max_s;
248
249 subject to const_5:(sum {(i,j) in {(19,-4),(19,-3),(19,-2),(19,-1)
          ,(19,0),(20,-7),(20,-6),(20,-5),
250   (20,-4),(20,-3),(20,-2),(20,-1),(20,0),(20,1),(20,2),(21,-8)
          ,(21,-7),(21,-6),(21,-5),
251   (21,-4),(21,-3),(21,-2),(21,-1),(21,0),(21,1),(21,2),(21,3)
          ,(22,-9),(22,-8),(22,-7),
252   (22,-6),(22,-5),(22,-4),(22,-3),(22,-2),(22,-1),(22,0),(22,1)
          ,(22,2),(22,3),(22,4),
253   (23,-10),(23,-9),(23,-8),(23,-7),(23,-6),(23,-5),(23,-4),(23,-3)
          ,(23,-2),(23,-1),(23,0),
254   (23,1),(23,2),(23,3),(24,-10),(24,-9),(24,-8),(24,-7),(24,-6)
          ,(24,-5),(24,-4),(24,-3),
255   (24,-2),(24,-1),(24,0),(24,1),(24,2),(24,3),(24,4),(25,-10)
          ,(25,-9),(25,-8),(25,-7),(25,-6),
256   (25,-5),(25,-4),(25,-3),(25,-2),(25,-1),(25,0),(25,1),(25,2)
          ,(25,3),(25,4),(26,-11),(26,-10),
257   (26,-9),(26,-8),(26,-7),(26,-6),(26,-5),(26,-4),(26,-3),(26,-2)
          ,(26,-1),(26,0),(26,1),(26,2),
258   (26,3),(27,-11),(27,-10),(27,-9),(27,-8),(27,-7),(27,-6),(27,-5)
          ,(27,-4),(27,-3),(27,-2),
259   (27,-1),(27,0),(27,1),(27,2),(27,3),(28,-11),(28,-10),(28,-9)
          ,(28,-8),(28,-7),(28,-6),
260   (28,-5),(28,-4),(28,-3),(28,-2),(28,-1),(28,0),(28,1),(28,2)
          ,(28,3),(29,-11),(29,-10),
261   (29,-9),(29,-8),(29,-7),(29,-6),(29,-5),(29,-4),(29,-3),(29,-2)
          ,(29,-1),(29,0),(29,1),
262   (29,2),(30,-10),(30,-9),(30,-8),(30,-7),(30,-6),(30,-5),(30,-4)
          ,(30,-3),(30,-2),(30,-1),
263   (30,0),(30,1),(30,2),(31,-9),(31,-8),(31,-7),(31,-6),(31,-5)
          ,(31,-4),(31,-3),(31,-2),
264   (31,-1),(31,0),(31,1),(31,2),(32,-8),(32,-7),(32,-6),(32,-5)
          ,(32,-4),(32,-3),(32,-2),
265   (32,-1),(32,0),(32,1),(33,-7),(33,-6),(33,-5),(33,-4),(33,-3)
          ,(33,-2),(33,-1),(33,0)
266 }} dose[i,j])*(0.00534759358) <= max_s;
267
268 #-----------------------------------------------------------
269 #we want to use the second one when we use many angles.
270 #subject to llodm{angle in ANGLES}:rad[angle,-max_odm] + rad[angle,
        max_odm] + sum{off in {-max_odm+1..max_odm}}t2[angle,off] <= 2*
        max_rad;
271
```

```
minimize amount:
 ( sum {angle in ANGLES, off in {-max_odm+1..max_odm}} t2[angle,off]) + ( sum {angle in ANGLES} (rad[angle,-max_odm] + rad[angle,max_odm])) ;
solve;

#START OPTIMIZING

#-------------------------------ANGLE 10-------------------------------------------------

subject to dynamic_constraint_10 {i in constraint_set_10}: rad[10,i] - rad[10,i+1] = 0;
let constraint_check := {};

for {derp in {1..40}} {
 let difference := 100; #reset difference to be arbitrarily large for iteration

 for {i in {-25..24} diff constraint_set_10} {
  if rad[10,i] = 0 or rad[10,i+1] = 0 then {

  } else {
   if abs(rad[10,i] - rad[10,i+1]) <= tolerance then {
    if abs(rad[10,i] - rad[10,i+1]) < difference then {
     let difference := abs(rad[10,i] - rad[10,i+1]);
     let tmp_offset := i;
    }
   }
  }
 }
 let constraint_set_10 := constraint_set_10 union {tmp_offset};

 solve;
}

#-------------------------ANGLE 50-------------------------------------------------

subject to dynamic_constraint_50 {i in constraint_set_50}: rad[50,i] - rad[50,i+1] = 0;
let constraint_check := {};

for {derp in {1..15}} {
 let difference := 100; #reset difference to be arbitrarily large for iteration

 for {i in {-25..24} diff constraint_set_50} {
  if rad[50,i] = 0 or rad[50,i+1] = 0 then {

  } else {
   if abs(rad[50,i] - rad[50,i+1]) <= tolerance then {
    if abs(rad[50,i] - rad[50,i+1]) < difference then {
     let difference := abs(rad[50,i] - rad[50,i+1]);
     let tmp_offset := i;
    }
   }
```

```
321   }
322  }
323  let constraint_set_50 := constraint_set_50 union {tmp_offset};
324
325  solve;
326 }
327
328 #---------------------------------ANGLE
      90-----------------------------------------------------
329
330 subject to dynamic_constraint_90 {i in constraint_set_90}: rad[90,i
      ] - rad[90,i+1] = 0;
331 let constraint_check := {};
332
333 for {derp in {1..5}} {
334  let difference := 100; #reset difference to be arbitrarily large
      for iteration
335
336  for {i in {-25..24} diff constraint_set_90} {
337   if rad[90,i] = 0 or rad[90,i+1] = 0 then {
338
339   } else {
340    if abs(rad[90,i] - rad[90,i+1]) <= tolerance then {
341     if abs(rad[90,i] - rad[90,i+1]) < difference then {
342      let difference := abs(rad[90,i] - rad[90,i+1]);
343      let tmp_offset := i;
344     }
345    }
346   }
347  }
348  let constraint_set_90 := constraint_set_90 union {tmp_offset};
349
350  solve;
351 }
352
353 #---------------------------------ANGLE
      170----------------------------------------------------
354
355 subject to dynamic_constraint_170 {i in constraint_set_170}: rad
      [90,i] - rad[90,i+1] = 0;
356 let constraint_check := {};
357
358 for {derp in {1..5}} {
359  let difference := 100; #reset difference to be arbitrarily large
      for iteration
360
361  for {i in {-25..24} diff constraint_set_170} {
362   if rad[90,i] = 0 or rad[90,i+1] = 0 then {
363
364   } else {
365    if abs(rad[90,i] - rad[90,i+1]) <= tolerance then {
366     if abs(rad[90,i] - rad[90,i+1]) < difference then {
367      let difference := abs(rad[90,i] - rad[90,i+1]);
368      let tmp_offset := i;
369     }
370    }
371   }
```

```
 }
 let constraint_set_170 := constraint_set_170 union {tmp_offset};

 solve;

}

#-------------------------------------------------------------
#printing output

printf "%7s: (", "Offset";
for {offset in -25..25} {
 printf "%7.2f, ",offset;
}
printf ")\n";

for {i in -25..24} {
 printf "----------";
}
printf "\n";

#print out beamlet values
for {angle in ANGLES} {
  printf "%7.2f: (", angle;
  for {offset in -25..25} {
    printf "%7.2f, ",rad[angle,offset];
    }
   printf ")\n";
}

printf "\n \n";

#print out Doses for all voxels
printf "Dose: (";
for {i in {-53..53}}{
  printf "(";
  for {j in {-75..75}}{
      printf "%7.2f, ",dose[i,j];
  }
  printf "),\n";
}

printf ")\n";
```

optimizer_final_ampl.py

Appendix B

Plotting Code

```
'''
Author: Ryan Martin

Last Modified by: Sari A.Latif
'''
import matplotlib.pyplot as plt
import numpy as np

#Inputs

#Tumour: 95 <= dose <= 105
tumour = ((-2,-4),(-2,-3),(-2,-2),(-2,-1),(-2,0),(-2,1),(-2,2)
    ,(-2,3),
 (-2,4),(-1,-8),(-1,-7),(-1,-6),(-1,-5),(-1,-4),(-1,-3),(-1,-2)
    ,(-1,-1),(-1,0),(-1,1),(-1,2),
 (-1,3),(-1,4),(-1,5),(0,-10),(0,-9),(0,-8),(0,-7),(0,-6),(0,-5)
    ,(0,-4),(0,-3),(0,-2),(0,-1),
 (0,0),(0,1),(0,2),(0,3),(0,4),(0,5),(0,6),(1,-11),(1,-10),(1,-9)
    ,(1,-8),(1,-7),(1,-6),(1,-5),
 (1,-4),(1,-3),(1,-2),(1,-1),(1,0),(1,1),(1,2),(1,3),(1,4),(1,5)
    ,(1,6),(1,7),(2,-12),(2,-11),
 (2,-10),(2,-9),(2,-8),(2,-7),(2,-6),(2,-5),(2,-4),(2,-3),(2,-2)
    ,(2,-1),(2,0),(2,1),(2,2),(2,3),
 (2,4),(2,5),(2,6),(2,7),(2,8),(3,-13),(3,-12),(3,-11),(3,-10)
    ,(3,-9),(3,-8),(3,-7),(3,-6),(3,-5),
 (3,-4),(3,-3),(3,-2),(3,-1),(3,0),(3,1),(3,2),(3,3),(3,4),(3,5)
    ,(3,6),(3,7),(3,8),(3,9),(4,-14),
 (4,-13),(4,-12),(4,-11),(4,-10),(4,-9),(4,-8),(4,-7),(4,-6),(4,-5)
    ,(4,-4),(4,-3),(4,-2),(4,-1),
 (4,0),(4,1),(4,2),(4,3),(4,4),(4,5),(4,6),(4,7),(4,8),(4,9),(4,10)
    ,(5,-14),(5,-13),(5,-12),(5,-11),
 (5,-10),(5,-9),(5,-8),(5,-7),(5,-6),(5,-5),(5,-4),(5,-3),(5,-2)
    ,(5,-1),(5,0),(5,1),(5,2),(5,3),(5,4),
 (5,5),(5,6),(5,7),(5,8),(5,9),(5,10),(6,-15),(6,-14),(6,-13)
    ,(6,-12),(6,-11),(6,-10),(6,-9),(6,-8),(6,-7),
 (6,-6),(6,-5),(6,-4),(6,-3),(6,-2),(6,-1),(6,0),(6,1),(6,2),(6,3)
    ,(6,4),(6,5),(6,6),(6,7),(6,8),(6,9),
```

```
25  (6,10),(7,-15),(7,-14),(7,-13),(7,-12),(7,-11),(7,-10),(7,-9)
        ,(7,-8),(7,-7),(7,-6),(7,-5),(7,-4),(7,-3),
26  (7,-2),(7,-1),(7,0),(7,1),(7,2),(7,3),(7,4),(7,5),(7,6),(7,7)
        ,(7,8),(7,9),(7,10),(7,11),(8,-15),(8,-14),
27  (8,-13),(8,-12),(8,-11),(8,-10),(8,-9),(8,-8),(8,-7),(8,-6),(8,-5)
        ,(8,-4),(8,-3),(8,-2),(8,-1),(8,0),
28  (8,1),(8,2),(8,3),(8,4),(8,5),(8,6),(8,7),(8,8),(8,9),(8,10)
        ,(8,11),(8,12),(9,-15),(9,-14),(9,-13),
29  (9,-12),(9,-11),(9,-10),(9,-9),(9,-8),(9,-7),(9,-6),(9,-5),(9,-4)
        ,(9,-3),(9,-2),(9,-1),(9,0),(9,1),
30  (9,2),(9,3),(9,4),(9,5),(9,6),(9,7),(9,8),(9,9),(9,10),(9,11)
        ,(9,12),(10,-15),(10,-14),(10,-13),(10,-12),
31  (10,-11),(10,-10),(10,-9),(10,-8),(10,-7),(10,-6),(10,-5),(10,-4)
        ,(10,-3),(10,-2),(10,-1),(10,0),(10,1),
32  (10,2),(10,3),(10,4),(10,5),(10,6),(10,7),(10,8),(10,9),(10,10)
        ,(10,11),(10,12),(11,-15),(11,-14),(11,-13),
33  (11,-12),(11,-11),(11,-10),(11,-9),(11,-8),(11,-7),(11,-6),(11,-5)
        ,(11,-4),(11,-3),(11,-2),(11,-1),(11,0),
34  (11,1),(11,2),(11,3),(11,4),(11,5),(11,6),(11,7),(11,8),(11,9)
        ,(11,10),(11,11),(11,12),(12,-15),(12,-14),
35  (12,-13),(12,-12),(12,-11),(12,-10),(12,-9),(12,-8),(12,-7)
        ,(12,-6),(12,-5),(12,-4),(12,-3),(12,-2),(12,-1),
36  (12,0),(12,1),(12,2),(12,3),(12,4),(12,5),(12,6),(12,7),(12,8)
        ,(12,9),(12,10),(12,11),(12,12),(13,-15),
37  (13,-14),(13,-13),(13,-12),(13,-11),(13,-10),(13,-9),(13,-8)
        ,(13,-7),(13,-6),(13,-5),(13,-4),(13,-3),
38  (13,-2),(13,-1),(13,0),(13,1),(13,2),(13,3),(13,4),(13,5),(13,6)
        ,(13,7),(13,8),(13,9),(13,10),(13,11),
39  (13,12),(14,-15),(14,-14),(14,-13),(14,-12),(14,-11),(14,-10)
        ,(14,-9),(14,-8),(14,-7),(14,-6),(14,-5),
40  (14,-4),(14,-3),(14,-2),(14,-1),(14,0),(14,1),(14,2),(14,3),(14,4)
        ,(14,5),(14,6),(14,7),(14,8),(14,9),
41  (14,10),(14,11),(14,12),(15,-15),(15,-14),(15,-13),(15,-12)
        ,(15,-11),(15,-10),(15,-9),(15,-8),(15,-7),
42  (15,-6),(15,-5),(15,-4),(15,-3),(15,-2),(15,-1),(15,0),(15,1)
        ,(15,2),(15,3),(15,4),(15,5),(15,6),(15,7),
43  (15,8),(15,9),(15,10),(15,11),(15,12),(16,-15),(16,-14),(16,-13)
        ,(16,-12),(16,-11),(16,-10),(16,-9),
44  (16,-8),(16,-7),(16,-6),(16,-5),(16,-4),(16,-3),(16,-2),(16,-1)
        ,(16,0),(16,1),(16,2),(16,3),(16,4),
45  (16,5),(16,6),(16,7),(16,8),(16,9),(16,10),(16,11),(16,12)
        ,(17,-15),(17,-14),(17,-13),(17,-12),(17,-11),
46  (17,-10),(17,-9),(17,-8),(17,-7),(17,-6),(17,-5),(17,-4),(17,-3)
        ,(17,-2),(17,-1),(17,0),(17,1),(17,2),
47  (17,3),(17,4),(17,5),(17,6),(17,7),(17,8),(17,9),(17,10),(17,11)
        ,(18,-14),(18,-13),(18,-12),(18,-11),
48  (18,-10),(18,-9),(18,-8),(18,-7),(18,-6),(18,-5),(18,-4),(18,-3)
        ,(18,-2),(18,-1),(18,0),(18,1),(18,2),
49  (18,3),(18,4),(18,5),(18,6),(18,7),(18,8),(18,9),(18,10),(18,11))
50
51 #Tissue type 1: Total Dose*(0.00179856115) <= 25
52 tissue1 = ((-25,-2),(-25,-1),(-24,-9),(-24,-8),(-24,-7),(-24,-6)
        ,(-24,-5),(-24,-4),
53  (-24,-3),(-24,-2),(-24,-1),(-24,0),(-24,1),(-24,2),(-24,3),(-24,4)
        ,(-23,-10),(-23,-9),(-23,-8),(-23,-7),
54  (-23,-6),(-23,-5),(-23,-4),(-23,-3),(-23,-2),(-23,-1),(-23,0)
        ,(-23,1),(-23,2),(-23,3),(-23,4),(-23,5),
```

```
55 (-23,6),(-22,-11),(-22,-10),(-22,-9),(-22,-8),(-22,-7),(-22,-6)
       ,(-22,-5),(-22,-4),(-22,-3),(-22,-2),
56 (-22,-1),(-22,0),(-22,1),(-22,2),(-22,3),(-22,4),(-22,5),(-22,6)
       ,(-22,7),(-22,8),(-21,-12),(-21,-11),
57 (-21,-10),(-21,-9),(-21,-8),(-21,-7),(-21,-6),(-21,-5),(-21,-4)
       ,(-21,-3),(-21,-2),(-21,-1),(-21,0),
58 (-21,1),(-21,2),(-21,3),(-21,4),(-21,5),(-21,6),(-21,7),(-21,8)
       ,(-21,9),(-21,10),(-20,-13),(-20,-12),
59 (-20,-11),(-20,-10),(-20,-9),(-20,-8),(-20,-7),(-20,-6),(-20,-5)
       ,(-20,-4),(-20,-3),(-20,-2),(-20,-1),
60 (-20,0),(-20,1),(-20,2),(-20,3),(-20,4),(-20,5),(-20,6),(-20,7)
       ,(-20,8),(-20,9),(-20,10),(-19,-13),
61 (-19,-12),(-19,-11),(-19,-10),(-19,-9),(-19,-8),(-19,-7),(-19,-6)
       ,(-19,-5),(-19,-4),(-19,-3),(-19,-2),
62 (-19,-1),(-19,0),(-19,1),(-19,2),(-19,3),(-19,4),(-19,5),(-19,6)
       ,(-19,7),(-19,8),(-19,9),(-19,10),
63 (-19,11),(-18,-13),(-18,-12),(-18,-11),(-18,-10),(-18,-9),(-18,-8)
       ,(-18,-7),(-18,-6),(-18,-5),(-18,-4),
64 (-18,-3),(-18,-2),(-18,-1),(-18,0),(-18,1),(-18,2),(-18,3),(-18,4)
       ,(-18,5),(-18,6),(-18,7),(-18,8),
65 (-18,9),(-18,10),(-18,11),(-17,-13),(-17,-12),(-17,-11),(-17,-10)
       ,(-17,-9),(-17,-8),(-17,-7),(-17,-6),
66 (-17,-5),(-17,-4),(-17,-3),(-17,-2),(-17,-1),(-17,0),(-17,1)
       ,(-17,2),(-17,3),(-17,4),(-17,5),(-17,6),
67 (-17,7),(-17,8),(-17,9),(-17,10),(-17,11),(-16,-13),(-16,-12)
       ,(-16,-11),(-16,-10),(-16,-9),(-16,-8),
68 (-16,-7),(-16,-6),(-16,-5),(-16,-4),(-16,-3),(-16,-2),(-16,-1)
       ,(-16,0),(-16,1),(-16,2),(-16,3),(-16,4),
69 (-16,5),(-16,6),(-16,7),(-16,8),(-16,9),(-16,10),(-16,11)
       ,(-15,-13),(-15,-12),(-15,-11),(-15,-10),
70 (-15,-9),(-15,-8),(-15,-7),(-15,-6),(-15,-5),(-15,-4),(-15,-3)
       ,(-15,-2),(-15,-1),(-15,0),(-15,1),(-15,2),
71 (-15,3),(-15,4),(-15,5),(-15,6),(-15,7),(-15,8),(-15,9),(-15,10)
       ,(-14,-12),(-14,-11),(-14,-10),(-14,-9),
72 (-14,-8),(-14,-7),(-14,-6),(-14,-5),(-14,-4),(-14,-3),(-14,-2)
       ,(-14,-1),(-14,0),(-14,1),(-14,2),(-14,3),
73 (-14,4),(-14,5),(-14,6),(-14,7),(-14,8),(-14,9),(-14,10),(-13,-12)
       ,(-13,-11),(-13,-10),(-13,-9),(-13,-8),
74 (-13,-7),(-13,-6),(-13,-5),(-13,-4),(-13,-3),(-13,-2),(-13,-1)
       ,(-13,0),(-13,1),(-13,2),(-13,3),(-13,4),
75 (-13,5),(-13,6),(-13,7),(-13,8),(-13,9),(-13,10),(-12,-12)
       ,(-12,-11),
76 (-12,-10),(-12,-9),(-12,-8),(-12,-7),(-12,-6),(-12,-5),(-12,-4)
       ,(-12,-3),(-12,-2),(-12,-1),(-12,0),
77 (-12,1),(-12,2),(-12,3),(-12,4),(-12,5),(-12,6),(-12,7),(-12,8)
       ,(-12,9),(-12,10),(-11,-12),(-11,-11),
78 (-11,-10),(-11,-9),(-11,-8),(-11,-7),(-11,-6),(-11,-5),(-11,-4)
       ,(-11,-3),(-11,-2),(-11,-1),(-11,0),
79 (-11,1),(-11,2),(-11,3),(-11,4),(-11,5),(-11,6),(-11,7),(-11,8)
       ,(-11,9),(-11,10),(-10,-12),(-10,-11),
80 (-10,-10),(-10,-9),(-10,-8),(-10,-7),(-10,-6),(-10,-5),(-10,-4)
       ,(-10,-3),(-10,-2),(-10,-1),(-10,0),
81 (-10,1),(-10,2),(-10,3),(-10,4),(-10,5),(-10,6),(-10,7),(-10,8)
       ,(-10,9),(-10,10),(-9,-12),(-9,-11),
82 (-9,-10),(-9,-9),(-9,-8),(-9,-7),(-9,-6),(-9,-5),(-9,-4),(-9,-3)
       ,(-9,-2),(-9,-1),(-9,0),(-9,1),(-9,2),
```

```
83  (-9,3),(-9,4),(-9,5),(-9,6),(-9,7),(-9,8),(-9,9),(-9,10),(-8,-12)
        ,(-8,-11),(-8,-10),(-8,-9),(-8,-8),
84  (-8,-7),(-8,-6),(-8,-5),(-8,-4),(-8,-3),(-8,-2),(-8,-1),(-8,0)
        ,(-8,1),(-8,2),(-8,3),(-8,4),(-8,5),
85  (-8,6),(-8,7),(-8,8),(-8,9),(-8,10),(-7,-13),(-7,-12),(-7,-11)
        ,(-7,-10),(-7,-9),(-7,-8),(-7,-7),
86  (-7,-6),(-7,-5),(-7,-4),(-7,-3),(-7,-2),(-7,-1),(-7,0),(-7,1)
        ,(-7,2),(-7,3),(-7,4),(-7,5),(-7,6),
87  (-7,7),(-7,8),(-7,9),(-7,10),(-6,-13),(-6,-12),(-6,-11),(-6,-10)
        ,(-6,-9),(-6,-8),(-6,-7),(-6,-6),
88  (-6,-5),(-6,-4),(-6,-3),(-6,-2),(-6,-1),(-6,0),(-6,1),(-6,2)
        ,(-6,3),(-6,4),(-6,5),(-6,6),(-6,7),
89  (-6,8),(-6,9),(-6,10),(-5,-13),(-5,-12),(-5,-11),(-5,-10),(-5,-9)
        ,(-5,-8),(-5,-7),(-5,-6),(-5,-5),
90  (-5,-4),(-5,-3),(-5,-2),(-5,-1),(-5,0),(-5,1),(-5,2),(-5,3),(-5,4)
        ,(-5,5),(-5,6),(-5,7),(-5,8),
91  (-5,9),(-5,10),(-4,-14),(-4,-13),(-4,-12),(-4,-11),(-4,-10)
        ,(-4,-9),(-4,-8),(-4,-7),(-4,-6),(-4,-5),
92  (-4,-4),(-4,-3),(-4,-2),(-4,-1),(-4,0),(-4,1),(-4,2),(-4,3),(-4,4)
        ,(-4,5),(-4,6),(-4,7),(-4,8),(-4,9),
93  (-4,10),(-3,-13),(-3,-12),(-3,-11),(-3,-10),(-3,-9),(-3,-8)
        ,(-3,-7),(-3,-6),(-3,-5),(-3,-4),(-3,-3),
94  (-3,-2),(-3,-1),(-3,0),(-3,1),(-3,2),(-3,3),(-3,4),(-3,5),(-3,6)
        ,(-3,7),(-3,8),(-3,9),(-3,10),(-3,11),
95  (-2,-13),(-2,-12),(-2,-11),(-2,-10),(-2,-9),(-2,-8),(-2,-7)
        ,(-2,-6),(-2,-5),(-2,5),(-2,6),(-2,7),(-2,8),
96  (-2,9),(-2,10),(-2,11),(-1,-14),(-1,-13),(-1,-12),(-1,-11)
        ,(-1,-10),(-1,-9),(-1,6),(-1,7),(-1,8),(-1,9),
97  (-1,10),(-1,11),(0,-14),(0,-13),(0,-12),(0,-11),(0,7),(0,8),(0,9)
        ,(0,10),(0,11),(1,-14),(1,-13),(1,-12),
98  (1,8),(1,9),(1,10),(1,11),(2,-14),(2,-13),(2,9),(2,10),(3,10))
99
100 #Tissue type 2: Total Dose*(0.00321543408) <= 25
101 tissue2 = ((-8,-35),(-8,-34),(-8,-33),(-8,-32),(-8,-31),(-7,-37)
        ,(-7,-36),
102 (-7,-35),(-7,-34),(-7,-33),(-7,-32),(-7,-31),(-7,-30),(-7,-29)
        ,(-6,-39),(-6,-38),(-6,-37),
103 (-6,-36),(-6,-35),(-6,-34),(-6,-33),(-6,-32),(-6,-31),(-6,-30)
        ,(-6,-29),(-6,-28),(-6,-27),
104 (-5,-40),(-5,-39),(-5,-38),(-5,-37),(-5,-36),(-5,-35),(-5,-34)
        ,(-5,-33),(-5,-32),(-5,-31),
105 (-5,-30),(-5,-29),(-5,-28),(-5,-27),(-5,-26),(-4,-41),(-4,-40)
        ,(-4,-39),(-4,-38),(-4,-37),
106 (-4,-36),(-4,-35),(-4,-34),(-4,-33),(-4,-32),(-4,-31),(-4,-30)
        ,(-4,-29),(-4,-28),(-4,-27),
107 (-4,-26),(-3,-41),(-3,-40),(-3,-39),(-3,-38),(-3,-37),(-3,-36)
        ,(-3,-35),(-3,-34),(-3,-33),
108 (-3,-32),(-3,-31),(-3,-30),(-3,-29),(-3,-28),(-3,-27),(-3,-26)
        ,(-3,-25),(-2,-42),(-2,-41),
109 (-2,-40),(-2,-39),(-2,-38),(-2,-37),(-2,-36),(-2,-35),(-2,-34)
        ,(-2,-33),(-2,-32),(-2,-31),
110 (-2,-30),(-2,-29),(-2,-28),(-2,-27),(-2,-26),(-2,-25),(-1,-42)
        ,(-1,-41),(-1,-40),(-1,-39),
111 (-1,-38),(-1,-37),(-1,-36),(-1,-35),(-1,-34),(-1,-33),(-1,-32)
        ,(-1,-31),(-1,-30),(-1,-29),
112 (-1,-28),(-1,-27),(-1,-26),(-1,-25),(0,-43),(0,-42),(0,-41)
        ,(0,-40),(0,-39),(0,-38),(0,-37),
```

```
113   (0,-36),(0,-35),(0,-34),(0,-33),(0,-32),(0,-31),(0,-30),(0,-29)
          ,(0,-28),(0,-27),(0,-26),
114   (0,-25),(0,-24),(1,-43),(1,-42),(1,-41),(1,-40),(1,-39),(1,-38)
          ,(1,-37),(1,-36),(1,-35),
115   (1,-34),(1,-33),(1,-32),(1,-31),(1,-30),(1,-29),(1,-28),(1,-27)
          ,(1,-26),(1,-25),(1,-24),
116   (2,-43),(2,-42),(2,-41),(2,-40),(2,-39),(2,-38),(2,-37),(2,-36)
          ,(2,-35),(2,-34),(2,-33),
117   (2,-32),(2,-31),(2,-30),(2,-29),(2,-28),(2,-27),(2,-26),(2,-25)
          ,(2,-24),(3,-43),(3,-42),
118   (3,-41),(3,-40),(3,-39),(3,-38),(3,-37),(3,-36),(3,-35),(3,-34)
          ,(3,-33),(3,-32),(3,-31),
119   (3,-30),(3,-29),(3,-28),(3,-27),(3,-26),(3,-25),(3,-24),(4,-43)
          ,(4,-42),(4,-41),(4,-40),
120   (4,-39),(4,-38),(4,-37),(4,-36),(4,-35),(4,-34),(4,-33),(4,-32)
          ,(4,-31),(4,-30),(4,-29),
121   (4,-28),(4,-27),(4,-26),(4,-25),(4,-24),(5,-42),(5,-41),(5,-40)
          ,(5,-39),(5,-38),(5,-37),
122   (5,-36),(5,-35),(5,-34),(5,-33),(5,-32),(5,-31),(5,-30),(5,-29)
          ,(5,-28),(5,-27),(5,-26),
123   (5,-25),(5,-24),(6,-42),(6,-41),(6,-40),(6,-39),(6,-38),(6,-37)
          ,(6,-36),(6,-35),(6,-34),
124   (6,-33),(6,-32),(6,-31),(6,-30),(6,-29),(6,-28),(6,-27),(6,-26)
          ,(6,-25),(7,-41),(7,-40),
125   (7,-39),(7,-38),(7,-37),(7,-36),(7,-35),(7,-34),(7,-33),(7,-32)
          ,(7,-31),(7,-30),(7,-29),
126   (7,-28),(7,-27),(7,-26),(7,-25),(8,-40),(8,-39),(8,-38),(8,-37)
          ,(8,-36),(8,-35),(8,-34),
127   (8,-33),(8,-32),(8,-31),(8,-30),(8,-29),(8,-28),(8,-27),(8,-26)
          ,(9,-39),(9,-38),(9,-37),
128   (9,-36),(9,-35),(9,-34),(9,-33),(9,-32),(9,-31),(9,-30),(9,-29)
          ,(9,-28),(9,-27),(10,-38),
129   (10,-37),(10,-36),(10,-35),(10,-34),(10,-33),(10,-32),(10,-31)
          ,(10,-30),(10,-29),(10,-28),
130   (11,-36),(11,-35),(11,-34),(11,-33),(11,-32),(11,-31),(11,-30))
131
132 #Tissue type 3: Total Dose*(0.00355871886) <= 25
133 tissue3 = ((-7,28),(-7,29),(-7,30),(-7,31),(-7,32),(-7,33),(-6,27)
          ,(-6,28),
134   (-6,29),(-6,30),(-6,31),(-6,32),(-6,33),(-6,34),(-5,25),(-5,26)
          ,(-5,27),(-5,28),(-5,29),
135   (-5,30),(-5,31),(-5,32),(-5,33),(-5,34),(-5,35),(-5,36),(-4,24)
          ,(-4,25),(-4,26),(-4,27),
136   (-4,28),(-4,29),(-4,30),(-4,31),(-4,32),(-4,33),(-4,34),(-4,35)
          ,(-4,36),(-4,37),(-3,23),
137   (-3,24),(-3,25),(-3,26),(-3,27),(-3,28),(-3,29),(-3,30),(-3,31)
          ,(-3,32),(-3,33),(-3,34),
138   (-3,35),(-3,36),(-3,37),(-2,22),(-2,23),(-2,24),(-2,25),(-2,26)
          ,(-2,27),(-2,28),(-2,29),
139   (-2,30),(-2,31),(-2,32),(-2,33),(-2,34),(-2,35),(-2,36),(-2,37)
          ,(-2,38),(-1,22),(-1,23),
140   (-1,24),(-1,25),(-1,26),(-1,27),(-1,28),(-1,29),(-1,30),(-1,31)
          ,(-1,32),(-1,33),(-1,34),
141   (-1,35),(-1,36),(-1,37),(-1,38),(0,22),(0,23),(0,24),(0,25),(0,26)
          ,(0,27),(0,28),(0,29),
142   (0,30),(0,31),(0,32),(0,33),(0,34),(0,35),(0,36),(0,37),(0,38)
          ,(0,39),(1,21),(1,22),(1,23),
```

```
143  (1,24),(1,25),(1,26),(1,27),(1,28),(1,29),(1,30),(1,31),(1,32)
         ,(1,33),(1,34),(1,35),(1,36),
144  (1,37),(1,38),(1,39),(2,21),(2,22),(2,23),(2,24),(2,25),(2,26)
         ,(2,27),(2,28),(2,29),(2,30),
145  (2,31),(2,32),(2,33),(2,34),(2,35),(2,36),(2,37),(2,38),(2,39)
         ,(3,21),(3,22),(3,23),(3,24),
146  (3,25),(3,26),(3,27),(3,28),(3,29),(3,30),(3,31),(3,32),(3,33)
         ,(3,34),(3,35),(3,36),(3,37),
147  (3,38),(3,39),(4,21),(4,22),(4,23),(4,24),(4,25),(4,26),(4,27)
         ,(4,28),(4,29),(4,30),(4,31),
148  (4,32),(4,33),(4,34),(4,35),(4,36),(4,37),(4,38),(4,39),(5,21)
         ,(5,22),(5,23),(5,24),(5,25),
149  (5,26),(5,27),(5,28),(5,29),(5,30),(5,31),(5,32),(5,33),(5,34)
         ,(5,35),(5,36),(5,37),(5,38),
150  (6,21),(6,22),(6,23),(6,24),(6,25),(6,26),(6,27),(6,28),(6,29)
         ,(6,30),(6,31),(6,32),(6,33),
151  (6,34),(6,35),(6,36),(6,37),(6,38),(7,22),(7,23),(7,24),(7,25)
         ,(7,26),(7,27),(7,28),(7,29),
152  (7,30),(7,31),(7,32),(7,33),(7,34),(7,35),(7,36),(7,37),(8,23)
         ,(8,24),(8,25),(8,26),(8,27),
153  (8,28),(8,29),(8,30),(8,31),(8,32),(8,33),(8,34),(8,35),(8,36)
         ,(9,24),(9,25),(9,26),(9,27),
154  (9,28),(9,29),(9,30),(9,31),(9,32),(9,33),(9,34),(9,35),(9,36)
         ,(10,25),(10,26),(10,27),
155  (10,28),(10,29),(10,30),(10,31),(10,32),(10,33),(10,34),(10,35)
         ,(11,27),(11,28),(11,29),
156  (11,30),(11,31),(11,32),(11,33),(11,34))
157
158 #Tissue type 4: Total Dose*(0.00534759358) <= 25
159 tissue4 = ((19,-4),(19,-3),(19,-2),(19,-1),(19,0),(20,-7),(20,-6)
         ,(20,-5),
160  (20,-4),(20,-3),(20,-2),(20,-1),(20,0),(20,1),(20,2),(21,-8)
         ,(21,-7),(21,-6),(21,-5),
161  (21,-4),(21,-3),(21,-2),(21,-1),(21,0),(21,1),(21,2),(21,3)
         ,(22,-9),(22,-8),(22,-7),
162  (22,-6),(22,-5),(22,-4),(22,-3),(22,-2),(22,-1),(22,0),(22,1)
         ,(22,2),(22,3),(22,4),
163  (23,-10),(23,-9),(23,-8),(23,-7),(23,-6),(23,-5),(23,-4),(23,-3)
         ,(23,-2),(23,-1),(23,0),
164  (23,1),(23,2),(23,3),(24,-10),(24,-9),(24,-8),(24,-7),(24,-6)
         ,(24,-5),(24,-4),(24,-3),
165  (24,-2),(24,-1),(24,0),(24,1),(24,2),(24,3),(24,4),(25,-10)
         ,(25,-9),(25,-8),(25,-7),(25,-6),
166  (25,-5),(25,-4),(25,-3),(25,-2),(25,-1),(25,0),(25,1),(25,2)
         ,(25,3),(25,4),(26,-11),(26,-10),
167  (26,-9),(26,-8),(26,-7),(26,-6),(26,-5),(26,-4),(26,-3),(26,-2)
         ,(26,-1),(26,0),(26,1),(26,2),
168  (26,3),(27,-11),(27,-10),(27,-9),(27,-8),(27,-7),(27,-6),(27,-5)
         ,(27,-4),(27,-3),(27,-2),
169  (27,-1),(27,0),(27,1),(27,2),(27,3),(28,-11),(28,-10),(28,-9)
         ,(28,-8),(28,-7),(28,-6),
170  (28,-5),(28,-4),(28,-3),(28,-2),(28,-1),(28,0),(28,1),(28,2)
         ,(28,3),(29,-11),(29,-10),
171  (29,-9),(29,-8),(29,-7),(29,-6),(29,-5),(29,-4),(29,-3),(29,-2)
         ,(29,-1),(29,0),(29,1),
172  (29,2),(30,-10),(30,-9),(30,-8),(30,-7),(30,-6),(30,-5),(30,-4)
         ,(30,-3),(30,-2),(30,-1),
```

```
173  (30,0),(30,1),(30,2),(31,-9),(31,-8),(31,-7),(31,-6),(31,-5)
         ,(31,-4),(31,-3),(31,-2),
174  (31,-1),(31,0),(31,1),(31,2),(32,-8),(32,-7),(32,-6),(32,-5)
         ,(32,-4),(32,-3),(32,-2),
175  (32,-1),(32,0),(32,1),(33,-7),(33,-6),(33,-5),(33,-4),(33,-3)
         ,(33,-2),(33,-1),(33,0))
176
177 #Rest of body
178 body = []
179 for x in xrange(-53,54):
180     for y in xrange(-75,76):
181         body.append((x,y))
182
183 #Plotting Tumor and Tissues
184 fig = plt.figure(1)
185 ax = fig.add_subplot(111,aspect='equal')
186
187 plt.scatter([x for (x,y) in body], [y for (x,y) in body],color='
        black',marker='s',label='Other body tissue/Plot surface')
188 plt.scatter([x for (x,y) in tumour], [y for (x,y) in tumour],color=
        'red',marker='s',label='Tumour: 95 <= Dose <=105')
189 plt.scatter([x for (x,y) in tissue1], [y for (x,y) in tissue1],
        color='blue',marker='s',label='Tissue type 1: Total Dose
        *(0.00179856115) <= 25')
190 plt.scatter([x for (x,y) in tissue2], [y for (x,y) in tissue2],
        color='yellow',marker='s',label='Tissue type 2: Total Dose
        *(0.00321543408) <= 25')
191 plt.scatter([x for (x,y) in tissue3], [y for (x,y) in tissue3],
        color='green',marker='s',label='Tissue type 3: Total Dose
        *(0.00355871886) <= 25')
192 plt.scatter([x for (x,y) in tissue4], [y for (x,y) in tissue4],
        color='cyan',marker='s',label='Tissue type 4: Total Dose
        *(0.00534759358) <= 25')
193
194 box = ax.get_position()
195 ax.set_xlim([-53,53])
196 ax.set_ylim([-75,75])
197 legend = ax.legend(loc='upper center',shadow=True,prop={'size':7})
198
199
200 #----------RESULTS----------
201
202 #7 Angles: 10, 50, 90, 130, 170, 200, 340
203 #Offsets for each angle: -25 to 25
204
205 a10= (   0.00,    0.00,    0.00,   28.60,   28.60,   28.60,
        28.60,   28.60,   23.02,   19.80,   15.91,   13.08,    8.25,
         8.25,    4.73,    4.73,    0.00,    0.00,    0.00,    0.00,
         0.00,    0.00,    0.00,    0.00,    2.70,    2.70,    2.70,
         2.70,    2.70,    2.70,    2.70,    0.00,    0.00,    0.00,
         0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
         0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
         0.00,    0.00,    0.00, )
206 a50= (   0.00,    0.00,    0.00,    0.00,    2.37,   10.77,
        17.49,   21.26,   23.62,   26.62,   32.61,   36.00,   36.00,
        36.00,   36.00,   36.00,   36.00,   36.00,   36.00,   36.00,
        35.72,   35.20,   35.17,   34.23,   33.84,   31.78,   30.64,
```

```
    29.43,   29.32,   29.98,    0.00,    0.00,    0.00,    0.00,
     0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
     0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
     0.00,    0.00,    0.00, )
a90= (   0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
    36.00,   36.00,   36.00,   34.38,   33.71,   30.05,   29.11,
    25.57,   22.68,   22.01,   21.74,   21.26,   20.45,   20.45,
    20.99,   22.33,   23.75,   24.76,   25.48,   25.98,   25.98,
    28.01,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
     0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
     0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
     0.00,    0.00,    0.00, )
a130= (   0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
    0.00,    0.00,    4.38,   14.06,   15.98,   20.40,   23.76,
    30.23,   34.59,   36.00,   36.00,   36.00,   36.00,   36.00,
    36.00,   36.00,   36.00,   36.00,   36.00,   34.99,   32.88,
    31.09,   30.40,   30.40,   29.93,   30.50,    0.00,    0.00,
     0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
     0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
     0.00,    0.00,    0.00, )
a170= (   0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
    0.00,    0.00,   -0.00,    0.00,    0.00,    8.97,    8.97,
    8.97,    6.31,    5.84,    5.84,    5.84,    1.10,    0.51,
    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
    0.00,    0.00,    0.00,    0.00,    3.21,    5.89,    5.89,
    4.38,    8.36,    0.00,    0.00,    0.00,    0.00,    0.00,
    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
    0.00,    0.00,    0.00, )
a200= (   0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
    0.93,    0.93,    0.00,    0.00,    0.00,    0.00,    0.06,
    1.27,    2.31,    1.64,    1.64,    0.45,    0.44,    0.44,
    2.52,    3.44,    1.38,    0.00,    0.00,    0.00,    0.00,
    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
    0.00,    0.00,    0.00, )
a340= (   0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
    0.00,    0.00,    2.01,    0.00,    0.00,    0.00,    1.28,
    4.01,    4.59,    4.59,    4.59,    2.74,    1.70,    1.58,
    0.02,    0.02,    0.00,    0.00,    0.00,    0.00,    0.00,
    0.00,    0.00,    2.96,    6.97,    7.83,   15.53,   15.53,
    15.53,   15.53,   15.53,    0.00,    0.00,    0.00,    0.00,
     0.00,    0.00,    0.00, )

#Dose ranges per voxel

Dose= ((  23.84,   23.85,   23.83,   23.76,   23.65,   23.67,
    23.73,   23.52,   23.26,   23.18,   23.09,   22.42,   21.79,
    21.44,   21.08,   20.69,   20.48,   20.50,   20.70,   21.02,
    12.53,    0.95,    0.00,    0.00,    0.00,    0.00,    0.00,
     0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
     0.00,    0.00,    0.00,    0.00,    0.00,    2.10,   20.59,
    21.75,   21.77,   21.79,   21.81,   21.23,   20.11,   19.58,
    14.88,   11.42,    8.82,    8.29,    8.02,    6.75,    5.16,
     0.84,    0.00,    0.00,    0.00,    0.74,    1.25,    0.30,
     0.00,    0.00,    1.18,    2.10,    2.10,    2.10,    2.10,
```

```
    2.10,   2.10,   2.11,   1.01,   0.00,   0.00,   4.59,
    8.20,   7.15,   7.81,   4.49,   0.00,   0.00,   1.23,
    0.59,   0.00,   0.00,   0.13,   0.95,   2.68,   3.60,
    4.59,   8.83,  11.23,  10.06,  10.13,  13.35,  12.83,
    6.17,   0.01,   0.00,   0.00,   0.00,   0.00,   0.00,
    0.00,   0.00,   0.00,   0.82,   2.76,   5.18,   5.73,
    9.27,  11.61,  11.59,  11.57,  11.55,  11.53,   7.02,
    0.00,   0.00,   0.00,   0.00,   0.00,   0.00,   0.00,
    0.00,   0.00,   0.00,   0.00,   0.00,  24.11,  46.49,
   46.17,  46.96,  47.29,  48.00,  49.54,  52.09,  55.04,
   56.84,  57.63,  57.91,  58.19,  58.47,  58.76,  59.04,
   59.33,  59.62,  59.91,  60.20,  60.49, ),
( 23.90,  23.97,  24.01,  23.99,  23.93,  23.83,  23.81,
   23.87,  23.73,  23.47,  23.35,  23.28,  22.70,  22.01,
   21.64,  21.28,  20.89,  20.61,  20.63,  20.78,  21.10,
   14.54,   2.86,   0.00,   0.00,   0.00,   0.00,   0.00,
    0.00,   0.00,   0.00,   0.00,   0.00,   0.00,   0.00,
    0.00,   0.00,   0.00,   0.00,   0.00,  16.33,  21.84,
   21.86,  21.88,  21.90,  21.83,  19.90,  20.55,  16.54,
   11.86,   9.52,   7.68,   8.51,   6.75,   5.75,   1.77,
    0.01,   0.00,   0.00,   0.23,   1.24,   0.81,   0.00,
    0.00,   0.86,   2.11,   2.11,   2.11,   2.11,   2.11,
    2.11,   2.12,   1.31,   0.00,   0.00,   7.08,   6.97,
    7.55,   7.69,   3.60,   0.00,   0.36,   1.48,   0.15,
    0.00,   0.00,   0.42,   1.53,   3.16,   3.86,   4.74,
    9.95,  10.78,   9.78,  10.50,  13.25,  12.40,   4.21,
    0.01,   0.00,   0.00,   0.00,   0.00,   0.00,   0.00,
    0.00,   0.00,   1.54,   3.74,   5.45,   6.53,  11.18,
   11.65,  11.63,  11.61,  11.59,  11.58,   3.21,   0.00,
    0.00,   0.00,   0.00,   0.00,   0.00,   0.00,   0.00,
    0.00,   0.00,   0.00,  32.19,  45.94,  45.89,  46.65,
   46.87,  47.76,  49.56,  52.15,  55.02,  56.58,  57.12,
   57.40,  57.67,  57.95,  58.23,  58.51,  58.80,  59.08,
   59.37,  59.65,  59.94,  58.26, ),
( 23.96,  24.03,  24.11,  24.17,  24.15,  24.11,  24.00,
   23.95,  24.02,  23.94,  23.68,  23.51,  23.45,  22.98,
   22.29,  21.85,  21.49,  21.10,  20.74,  20.76,  20.86,
   21.18,  16.58,   4.80,   0.00,   0.00,   0.00,   0.00,
    0.00,   0.00,   0.00,   0.00,   0.00,   0.00,   0.00,
    0.00,   0.00,   0.00,   0.00,   0.00,  12.01,  21.93,
   21.95,  21.98,  22.00,  22.02,  20.08,  20.08,  17.81,
   12.72,  10.24,   7.12,   8.61,   6.89,   6.30,   3.05,
    0.04,   0.00,   0.00,   0.00,   1.06,   1.23,   0.00,
    0.00,   0.53,   2.12,   2.12,   2.12,   2.12,   2.12,
    2.12,   2.12,   1.62,   0.00,   0.00,   9.53,   5.76,
    7.71,   6.88,   2.67,   0.00,   0.81,   1.03,   0.00,
    0.00,   0.00,   0.71,   2.16,   3.31,   4.04,   4.89,
   11.05,  10.32,   9.61,  11.02,  12.95,  11.98,   2.28,
    0.00,   0.00,   0.00,   0.00,   0.00,   0.00,   0.00,
    0.00,   0.44,   2.27,   4.73,   5.68,   8.45,  11.72,
   11.70,  11.68,  11.66,  11.64,   8.64,   0.00,   0.00,
    0.00,   0.00,   0.00,   0.00,   0.00,   0.00,   0.00,
    0.00,   4.78,  40.06,  45.39,  45.62,  46.25,  46.47,
   47.51,  49.57,  52.21,  54.78,  56.32,  56.62,  56.89,
   57.16,  57.44,  57.71,  57.99,  58.27,  58.55,  58.83,
   59.12,  59.18,  57.47,  51.79, ),
```

```
218 (  24.02,  24.10,  24.17,  24.25,  24.33,  24.31,  24.29,
       24.18,  24.09,  24.16,  24.15,  23.89,  23.68,  23.61,
       23.26,  22.57,  22.06,  21.70,  21.31,  20.91,  20.89,
       20.94,  21.26,  18.66,   6.79,   0.00,   0.00,   0.00,
        0.00,   0.00,   0.00,   0.00,   0.00,   0.00,   0.00,
        0.00,   0.00,   0.00,   0.00,   0.00,   7.63,  22.03,
       22.05,  22.07,  22.09,  22.11,  20.29,  19.57,  18.87,
       14.23,  10.88,   7.73,   8.26,   7.16,   6.74,   4.33,
        0.07,   0.00,   0.00,   0.00,   0.56,   1.23,   0.48,
        0.00,   0.20,   2.05,   2.13,   2.13,   2.13,   2.13,
        2.13,   2.13,   1.93,   0.06,   0.00,  10.35,   6.13,
        7.67,   6.08,   1.76,   0.00,   1.26,   0.59,   0.00,
        0.00,   0.16,   1.00,   2.80,   3.45,   4.17,   5.04,
       11.05,   9.85,   9.44,  11.53,  12.52,  11.91,   0.38,
        0.00,   0.00,   0.00,   0.00,   0.00,   0.00,   0.00,
        0.00,   1.17,   3.26,   5.40,   5.92,  10.38,  11.77,
       11.75,  11.73,  11.71,  11.69,   4.77,   0.00,   0.00,
        0.00,   0.00,   0.00,   0.00,   0.00,   0.00,   0.00,
       12.84,  45.29,  44.86,  45.35,  45.85,  46.23,  47.27,
       49.57,  52.26,  54.54,  55.85,  56.12,  56.39,  56.66,
       56.93,  57.20,  57.47,  57.75,  58.03,  58.31,  58.59,
       58.39,  56.43,  50.56,  41.93, ),
219 (  24.08,  24.16,  24.24,  24.31,  24.39,  24.47,  24.48,
       24.46,  24.37,  24.26,  24.30,  24.37,  24.10,  23.85,
       23.78,  23.55,  22.85,  22.28,  21.91,  21.53,  21.12,
       21.03,  21.05,  21.35,  20.77,   8.80,   0.00,   0.00,
        0.00,   0.00,   0.00,   0.00,   0.00,   0.00,   0.00,
        0.00,   0.00,   0.00,   0.00,   0.00,   3.20,  22.12,
       22.14,  22.16,  22.19,  22.21,  20.90,  19.17,  19.94,
       15.81,  11.33,   8.45,   7.67,   7.66,   6.40,   5.53,
        0.64,   0.02,   0.00,   0.00,   0.07,   1.22,   0.98,
        0.00,   0.00,   1.73,   2.14,   2.14,   2.14,   2.14,
        2.14,   2.14,   2.15,   0.36,   2.26,   9.14,   6.53,
        7.63,   5.29,   0.86,   0.36,   1.49,   0.13,   0.00,
        0.00,   0.45,   1.63,   3.23,   3.60,   4.31,   6.14,
       10.59,   9.57,   9.35,  12.04,  12.08,  11.85,   0.01,
        0.00,   0.00,   0.00,   0.00,   0.00,   0.00,   0.00,
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       11.79,  11.77,  11.75,  10.29,   0.86,   0.00,   0.00,
        0.00,   0.00,   0.00,   0.00,   0.00,   0.00,  20.69,
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       52.30,  54.30,  55.37,  55.63,  55.89,  56.16,  56.43,
       56.70,  56.97,  57.24,  57.51,  57.79,  58.06,  57.61,
       55.16,  49.32,  40.48,  35.22, ),
220 (  24.14,  24.22,  24.30,  24.38,  24.45,  24.53,  24.61,
       24.64,  24.62,  24.55,  24.44,  24.45,  24.51,  24.31,
       24.04,  23.95,  23.85,  23.14,  22.49,  22.12,  21.74,
       21.34,  21.16,  21.18,  21.43,  21.77,  10.85,   0.00,
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        0.00,   0.00,   0.00,   0.00,   0.00,   0.00,  17.83,
       22.24,  22.26,  22.28,  22.30,  21.83,  19.07,  19.48,
       17.03,  12.25,   9.17,   7.09,   8.17,   6.06,   6.41,
        1.91,   0.05,   0.00,   0.00,   0.00,   0.88,   1.21,
        0.17,   0.00,   1.40,   2.14,   2.15,   2.15,   2.15,
        2.15,   2.15,   2.15,   0.67,   4.68,   7.94,   6.92,
        7.59,   4.52,   0.00,   0.82,   1.03,   0.00,   0.00,
        0.00,   0.75,   2.28,   3.37,   3.70,   4.46,   7.25,
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    10.12,   9.29,   9.39,  12.22,  11.77,  10.06,   0.00,
     0.00,   0.00,   0.00,   0.00,   0.00,   0.00,   0.00,
     0.78,   2.77,   5.28,   5.87,   9.56,  11.88,  11.86,
    11.84,  11.82,  11.80,   6.39,   0.00,   0.00,   0.00,
     0.00,   0.00,   0.00,   0.00,   0.00,  28.34,  44.24,
    44.07,  44.81,  45.06,  45.77,  47.23,  49.59,  52.33,
    54.06,  54.89,  55.15,  55.41,  55.67,  55.93,  56.20,
    56.46,  56.73,  57.00,  57.27,  57.54,  56.85,  53.92,
    47.80,  39.07,  34.38,  28.61, ),
( 24.21,  24.28,  24.36,  24.44,  24.52,  24.60,  24.68,
    24.76,  24.81,  24.79,  24.74,  24.63,  24.60,  24.66,
    24.53,  24.25,  24.12,  24.05,  23.43,  22.71,  22.34,
    21.96,  21.55,  21.29,  21.32,  21.51,  21.85,  12.94,
     0.66,   0.00,   0.00,   0.00,   0.00,   0.00,   0.00,
     0.00,   0.00,   0.00,   0.00,   0.00,   0.00,  13.40,
    22.33,  22.36,  22.38,  22.40,  22.42,  19.31,  19.01,
    18.09,  13.74,   9.90,   7.09,   8.23,   6.26,   6.68,
     3.17,   0.08,   0.00,   0.00,   0.00,   0.39,   1.21,
     0.65,   0.00,   1.06,   2.15,   2.16,   2.16,   2.16,
     2.16,   2.16,   2.16,   0.98,   7.06,   6.77,   7.30,
     7.54,   3.69,   0.00,   1.29,   0.58,   0.00,   0.00,
     0.19,   1.09,   2.93,   3.52,   3.83,   4.61,   7.98,
     9.69,   9.01,   9.42,  12.21,  11.70,   8.14,   0.00,
     0.00,   0.00,   0.00,   0.00,   0.00,   0.00,   0.00,
     1.52,   3.79,   5.58,   6.72,  11.54,  11.93,  11.91,
    11.89,  11.87,  11.85,   2.43,   0.00,   0.00,   0.00,
     0.00,   0.00,   0.00,   2.53,  35.80,  43.72,  43.81,
    44.47,  44.68,  45.54,  47.24,  49.65,  52.36,  53.82,
    54.41,  54.67,  54.93,  55.18,  55.44,  55.71,  55.97,
    56.23,  56.50,  56.77,  57.03,  56.10,  52.70,  46.31,
    38.01,  33.55,  27.70,  24.19, ),
( 24.27,  24.35,  24.42,  24.50,  24.58,  24.66,  24.74,
    24.82,  24.90,  24.98,  24.96,  24.93,  24.81,  24.74,
    24.81,  24.75,  24.47,  24.30,  24.23,  23.73,  23.00,
    22.56,  22.18,  21.77,  21.43,  21.46,  21.60,  21.94,
    15.07,   2.68,   0.00,   0.00,   0.00,   0.00,   0.00,
     0.00,   0.00,   0.00,   0.00,   0.00,   0.00,   8.91,
    22.43,  22.45,  22.47,  22.50,  22.52,  19.92,  18.64,
    19.14,  15.21,  10.65,   7.32,   7.66,   6.77,   6.34,
     4.34,   0.63,   0.02,   0.00,   0.00,   0.00,   1.19,
     1.13,   0.00,   0.73,   2.16,   2.17,   2.17,   2.17,
     2.17,   2.17,   2.17,   1.30,   9.41,   5.61,   7.49,
     6.80,   2.80,   0.37,   1.50,   0.11,   0.00,   0.00,
     0.49,   1.74,   3.29,   3.67,   3.97,   4.76,   8.60,
     9.41,   8.88,   9.62,  11.77,  11.64,   6.25,   0.00,
     0.00,   0.00,   0.00,   0.00,   0.00,   0.00,   0.39,
     2.28,   4.81,   5.82,   8.71,  12.00,  11.98,  11.96,
    11.94,  11.92,   8.04,   0.00,   0.00,   0.00,   0.00,
     0.00,   0.00,  10.16,  43.07,  43.22,  43.55,  44.10,
    44.34,  45.31,  47.25,  49.70,  52.15,  53.58,  53.94,
    54.20,  54.45,  54.71,  54.96,  55.22,  55.48,  55.74,
    56.00,  56.27,  56.53,  55.36,  51.51,  44.85,  37.15,
    32.72,  26.80,  23.70,  13.81, ),
( 24.33,  24.41,  24.49,  24.57,  24.65,  24.72,  24.80,
    24.89,  24.97,  25.05,  25.13,  25.13,  25.11,  25.00,
    24.89,  24.96,  24.97,  24.69,  24.47,  24.40,  24.03,
    23.29,  22.78,  22.40,  21.99,  21.57,  21.59,  21.68,
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    22.03,   17.23,    4.74,    0.00,    0.00,    0.00,    0.00,
     0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    4.37,
    22.53,   22.55,   22.57,   22.59,   22.62,   20.86,   18.53,
    18.78,   16.24,   11.76,    8.05,    7.15,    7.28,    6.01,
     5.52,    1.23,    0.06,    0.00,    0.00,    0.00,    0.71,
     1.19,    0.34,    0.38,    2.17,    2.18,    2.18,    2.18,
     2.18,    2.18,    2.18,    1.71,   10.00,    5.94,    7.45,
     6.03,    1.93,    0.84,    1.03,    0.00,    0.00,    0.00,
     0.79,    2.40,    3.44,    3.68,    4.10,    4.90,    9.20,
     9.12,    8.89,    9.76,   11.56,   11.57,    4.40,    0.00,
     0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    1.14,
     3.29,    5.52,    6.06,   10.71,   12.05,   12.03,   12.01,
    11.99,   11.97,    4.04,    0.00,    0.00,    0.00,    0.00,
     0.00,   17.60,   43.13,   42.72,   43.30,   43.73,   44.12,
    45.09,   47.26,   49.75,   51.93,   53.23,   53.48,   53.73,
    53.98,   54.23,   54.49,   54.74,   55.00,   55.25,   55.51,
    55.77,   56.03,   54.64,   50.34,   43.43,   36.30,   31.78,
    25.93,   23.22,   12.40,    3.41, ),
( 24.39,   24.47,   24.55,   24.63,   24.71,   24.79,   24.87,
    24.95,   25.03,   25.11,   25.19,   25.28,   25.30,   25.28,
    25.19,   25.08,   25.11,   25.18,   24.91,   24.65,   24.58,
    24.33,   23.59,   23.01,   22.62,   22.21,   21.79,   21.73,
    21.77,   22.11,   19.44,    6.84,    0.00,    0.00,    0.00,
     0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
    19.41,   22.65,   22.67,   22.69,   22.72,   21.81,   18.44,
    18.42,   17.28,   13.21,    8.79,    7.17,    7.29,    5.91,
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     2.19,    2.19,    2.19,    4.39,    8.84,    6.32,    7.41,
     5.28,    1.06,    1.31,    0.57,    0.00,    0.00,    0.22,
     1.18,    3.06,    3.60,    3.70,    4.23,    4.60,    9.53,
     8.83,    8.92,    9.90,   11.50,   11.50,    2.58,    0.00,
     0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    1.90,
     4.33,    5.77,    7.83,   12.12,   12.10,   12.08,   12.05,
    12.03,    9.75,    0.00,    0.00,    0.00,    0.00,    0.00,
    24.86,   42.63,   42.35,   43.05,   43.36,   43.91,   45.05,
    47.26,   49.79,   51.71,   52.78,   53.02,   53.27,   53.52,
    53.77,   54.02,   54.27,   54.52,   54.77,   55.03,   55.29,
    55.47,   53.92,   49.20,   42.04,   35.47,   30.85,   25.23,
    22.75,   11.02,    2.83,    0.00, ),
( 24.45,   24.53,   24.61,   24.69,   24.77,   24.85,   24.93,
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    25.45,   25.39,   25.27,   25.27,   25.33,   25.14,   24.85,
    24.76,   24.64,   23.89,   23.23,   22.84,   22.44,   22.01,
    21.87,   21.90,   22.20,   21.68,    8.98,    0.00,    0.00,
     0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
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    18.08,   18.30,   14.66,    9.55,    7.20,    7.24,    5.92,
     6.29,    3.10,    0.75,    0.03,    0.00,    0.00,    0.00,
     1.01,    1.18,    0.04,    1.63,    2.19,    2.20,    2.20,
     2.20,    2.20,    2.20,    6.96,    8.01,    6.70,    7.37,
     4.54,    0.59,    1.51,    0.09,    0.00,    0.00,    0.53,
     1.85,    3.36,    3.72,    3.71,    4.36,    4.90,    9.24,
     8.76,    8.79,   10.02,   11.44,   11.44,    0.79,    0.00,
     0.00,    0.00,    0.00,    0.00,    0.00,    0.74,    2.78,
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    12.08,    5.70,    0.00,    0.00,    0.00,    0.52,   31.93,
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    53.55,   53.80,   54.05,   54.30,   54.55,   54.81,   54.75,
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( 24.52,   24.60,   24.68,   24.76,   24.84,   24.92,   25.00,
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    25.65,   25.63,   25.58,   25.47,   25.42,   25.49,   25.37,
    25.08,   24.94,   24.86,   24.20,   23.46,   23.07,   22.67,
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     0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
    10.26,   22.85,   22.87,   22.89,   22.91,   22.94,   19.84,
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     2.21,    2.21,    2.21,    9.25,    7.20,    7.07,    7.33,
     3.77,    0.86,    1.03,    0.00,    0.00,    0.00,    0.84,
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     8.69,    8.46,   10.48,   11.37,   11.37,    0.00,    0.00,
     0.00,    0.00,    0.00,    0.00,    0.00,    1.51,    3.84,
     5.71,    6.93,   11.92,   12.21,   12.19,   12.17,   12.15,
    11.51,    1.59,    0.00,    0.00,    7.75,   38.82,   41.67,
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    51.26,   51.89,   52.13,   52.37,   52.61,   52.85,   53.10,
    53.34,   53.59,   53.83,   54.08,   54.33,   54.05,   52.23,
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     1.71,    0.00,    0.00,    0.00, ),
( 24.58,   24.66,   24.74,   24.82,   24.90,   24.98,   25.06,
    25.15,   25.23,   25.31,   25.39,   25.48,   25.56,   25.65,
    25.73,   25.81,   25.81,   25.78,   25.66,   25.58,   25.65,
    25.60,   25.31,   25.12,   25.04,   24.51,   23.75,   23.30,
    22.90,   22.47,   22.16,   22.18,   22.38,   22.74,   13.37,
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     0.09,    1.16,    0.97,    0.93,    2.21,    2.22,    2.22,
     2.22,    2.22,    2.22,   11.51,    6.42,    7.28,    6.72,
     2.92,    1.34,    0.55,    0.00,    0.00,    0.26,    1.28,
     3.20,    3.67,    3.75,    3.91,    4.09,    6.20,    8.71,
     8.63,    8.12,   10.97,   11.30,    9.89,    0.00,    0.00,
     0.00,    0.00,    0.00,    0.00,    0.33,    2.29,    4.90,
     5.96,    8.98,   12.29,   12.27,   12.24,   12.22,   12.20,
     7.40,    0.00,    0.00,   14.81,   41.58,   41.19,   41.63,
    42.09,   42.35,   43.27,   45.10,   47.38,   49.71,   51.04,
    51.45,   51.69,   51.93,   52.16,   52.40,   52.64,   52.89,
    53.13,   53.37,   53.62,   53.86,   53.35,   51.10,   45.92,
    38.06,   33.09,   28.19,   23.79,   19.71,    7.09,    1.17,
     0.00,    0.00,    0.00,    0.00, ),
( 23.38,   24.64,   24.80,   24.88,   24.97,   25.05,   25.13,
    25.21,   25.29,   25.38,   25.46,   25.54,   25.63,   25.71,
    25.80,   25.88,   25.97,   25.98,   25.96,   25.86,   25.74,
    25.80,   25.83,   25.54,   25.30,   25.23,   24.83,   24.06,
    23.53,   23.13,   22.70,   22.30,   22.33,   22.47,   22.83,
    15.63,    2.47,    0.00,    0.00,    0.00,    0.00,    0.00,
     0.87,   21.06,   23.07,   23.09,   23.12,   23.14,   21.78,
    18.17,   17.46,   17.41,   14.09,    8.40,    7.28,    6.28,
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    2.23,   2.23,   2.58,  11.91,   7.05,   7.24,   5.98,
    2.46,   1.52,   0.07,   0.00,   0.00,   0.57,   1.96,
    3.43,   3.77,   3.77,   4.04,   3.76,   6.95,   8.64,
    8.30,   7.87,  11.24,  11.24,   8.09,   0.00,   0.00,
    0.00,   0.00,   0.00,   0.00,   1.10,   3.32,   5.65,
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   42.15,  43.05,  45.10,  47.42,  49.50,  50.79,  51.02,
   51.26,  51.49,  51.72,  51.96,  52.20,  52.44,  52.68,
   52.92,  53.16,  53.40,  52.67,  49.99,  44.59,  36.79,
   32.33,  27.34,  23.33,  18.31,   6.36,   0.65,   0.00,
    0.00,   0.00,   0.00,   0.00, ),
(  21.56,  23.18,  24.45,  24.95,  25.03,  25.11,  25.19,
   25.28,  25.36,  25.44,  25.53,  25.61,  25.70,  25.78,
   25.87,  25.95,  26.04,  26.12,  26.16,  26.14,  26.06,
   25.94,  25.96,  26.03,  25.77,  25.49,  25.41,  25.15,
   24.37,  23.77,  23.36,  22.93,  22.49,  22.48,  22.55,
   22.92,  17.92,   4.66,   0.00,   0.00,   0.00,   0.00,
    0.00,  16.40,  23.17,  23.19,  23.22,  23.24,  22.76,
   18.77,  17.43,  17.12,  15.05,   9.81,   7.31,   6.45,
    5.85,   5.65,   2.97,   1.43,   0.07,   0.00,   0.00,
    0.00,   0.39,   1.15,   0.89,   2.22,   2.24,   2.24,
    2.24,   2.24,   4.85,  10.80,   7.75,   7.20,   5.26,
    2.12,   1.03,   0.00,   0.00,   0.00,   0.89,   2.65,
    3.59,   3.79,   3.78,   3.97,   3.43,   7.68,   8.57,
    7.87,   8.25,  11.17,  11.17,   6.31,   0.00,   0.00,
    0.00,   0.00,   0.00,   0.00,   1.89,   4.40,   5.90,
    8.07,  12.41,  12.39,  12.37,  12.35,  12.32,   9.16,
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    0.00,   0.00,   0.00,   0.00, ),
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   25.94,  26.02,  26.11,  26.19,  26.28,  26.35,  26.33,
   26.27,  26.15,  26.12,  26.20,  26.01,  25.71,  25.60,
   25.47,  24.69,  24.01,  23.60,  23.17,  22.72,  22.62,
   22.65,  23.01,  20.27,   6.88,   0.00,   0.00,   0.00,
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    5.30,   5.95,   3.44,   1.93,   0.42,   0.01,   0.00,
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    2.25,   2.25,   7.08,   9.71,   8.45,   7.17,   4.55,
    1.81,   0.54,   0.00,   0.00,   0.29,   1.38,   3.34,
    3.75,   3.81,   3.80,   3.62,   3.28,   8.50,   8.51,
    7.53,   8.74,  11.11,  11.11,   4.57,   0.00,   0.00,
    0.00,   0.00,   0.00,   0.69,   2.80,   5.49,   6.16,
   10.18,  12.46,  12.44,  12.42,  12.40,  12.38,  10.53,
   34.96,  40.20,  40.27,  40.88,  41.07,  41.75,  43.06,
   45.11,  47.49,  49.09,  49.95,  50.18,  50.40,  50.63,
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   26.51,   26.47,   26.35,   26.29,   26.36,   26.25,   25.94,
   25.79,   25.71,   25.01,   24.25,   23.84,   23.41,   22.96,
   22.77,   22.80,   23.11,   22.65,    9.15,    0.00,    0.00,
    0.00,    6.89,   23.37,   23.40,   23.42,   23.45,   23.47,
   20.73,   17.63,   16.67,   16.73,   13.24,    7.36,    7.37,
    5.28,    5.96,    3.82,    2.41,    0.97,    0.04,    0.00,
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    2.26,    2.26,    9.27,    8.65,    9.11,    7.38,    4.23,
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    7.39,    9.22,   11.04,   11.05,    2.85,    0.00,    0.00,
    0.00,    0.00,    0.00,    1.49,    3.89,    5.85,    7.13,
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( 16.05,   17.09,   18.21,   20.09,   22.31,   23.85,   25.16,
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   26.07,   26.16,   26.25,   26.34,   26.42,   26.51,   26.60,
   26.69,   26.70,   26.67,   26.56,   26.45,   26.52,   26.49,
   26.19,   25.98,   25.91,   25.34,   24.53,   24.08,   23.65,
   23.20,   22.92,   22.95,   23.20,   23.58,   11.46,    0.00,
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    7.44,    9.69,   10.98,   10.99,    1.16,    0.00,    0.00,
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    0.00,    0.00,    0.00,    0.00, ),
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   26.14,   26.23,   26.32,   26.41,   26.49,   26.58,   26.67,
   26.76,   26.85,   26.88,   26.86,   26.77,   26.64,   26.69,
   26.74,   26.43,   26.18,   26.10,   25.67,   24.86,   24.32,
   23.90,   23.44,   23.07,   23.10,   23.29,   23.67,   13.82,
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    0.00,    0.00,    0.00,    0.97,    1.91,    2.37,    2.28,
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     48.73,   48.95,   49.17,   49.39,   49.61,   49.83,   50.05,
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      0.00,    0.00,    0.00,    0.00, ),
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     26.83,   26.92,   27.02,   27.07,   27.05,   26.98,   26.85,
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     24.57,   24.14,   23.69,   23.23,   23.26,   23.39,   23.77,
     16.22,    2.23,   13.17,   23.71,   23.74,   23.76,   23.78,
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      0.02,    0.00,    0.00,    0.66,    2.20,    3.57,    3.88,
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     26.91,   27.00,   27.09,   27.18,   27.27,   27.24,   27.20,
     27.07,   27.03,   27.10,   26.93,   26.61,   26.49,   26.35,
     25.52,   24.82,   24.39,   23.94,   23.46,   23.41,   23.48,
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    23.73,   23.76,   24.07,   43.40,   33.38,   24.08,   24.10,
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     8.50,   10.68,   10.68,    4.71,    0.00,    0.00,    0.00,
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    50.40,   50.97,   51.28,   44.72,   39.56,   41.20,   43.19,
    45.31,   46.47,   46.97,   47.17,   47.38,   47.59,   47.79,
    48.00,   48.21,   48.43,   48.64,   48.85,   49.07,   49.28,
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     0.00,    0.00,    0.00,    0.00, ),
(    1.38,    3.68,    6.70,    9.34,   11.81,   13.51,   14.94,
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    27.78,   27.83,   27.81,   27.72,   27.59,   27.62,   27.70,
    27.37,   27.10,   27.02,   26.55,   25.70,   25.16,   24.71,
    24.22,   23.89,   23.92,   38.90,   48.73,   35.97,   24.21,
    24.24,   23.76,   19.52,   17.08,   15.11,   14.99,   12.02,
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     8.95,   10.62,   10.63,    3.09,    0.00,    0.00,    0.00,
     1.03,    3.38,    5.93,    8.40,   40.01,   50.43,   50.28,
    50.84,   51.06,   50.88,   40.86,   41.21,   43.23,   45.13,
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    47.82,   48.03,   48.24,   48.45,   48.66,   48.88,   47.75,
    44.54,   39.32,   32.65,   29.12,   24.64,   21.27,   16.93,
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    27.20,   27.29,   27.39,   27.48,   27.57,   27.67,   27.76,
    27.86,   27.95,   28.03,   28.01,   27.95,   27.81,   27.80,
    27.88,   27.63,   27.31,   27.22,   26.91,   26.05,   25.42,
    24.97,   24.48,   24.05,   33.77,   48.54,   48.97,   38.61,
    24.35,   24.37,   20.55,   17.70,   15.24,   14.64,   13.22,
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    46.22,   46.42,   46.62,   46.82,   47.03,   47.23,   47.44,
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       28.56,   28.66,   28.76,   28.86,   28.96,   29.06,   29.17,
       29.27,   29.37,   29.48,   29.58,   29.68,   29.79,   29.88,
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       41.06,   39.08,   35.05,   42.47,   38.07,   39.45,   37.91,
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    21.37,   21.47,   21.57,   21.67,   21.78,   21.88,   21.98,
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    20.80,   20.90,   20.99,   21.09,   21.18,   21.28,   21.37,
    21.47,   21.57,   21.67,   21.77,   22.59,   23.87,   27.71,
    31.97,   35.50,   38.57,   40.66,   42.35,   43.76,   45.47,
    47.46,   50.84,   53.67,   71.75,   84.44,   84.70,   84.97,
    85.24,   83.26,   79.08,   76.04,   72.91,   69.88,   66.78,
    67.04,   71.57,   95.00,   95.00,   95.00,   95.45,   95.24,
    95.55,   96.36,   97.03,   97.15,   97.77,   97.15,   97.34,
    95.95,   95.36,   96.28,   97.02,   95.26,   78.48,   69.61,
    70.34,   70.63,   72.03,   77.58,   81.54,   82.60,   81.87,
    80.65,   78.96,   76.00,   71.48,   60.94,   50.75,   47.63,
    45.73,   43.02,   35.69,   31.71,   29.88,   30.04,   30.20,
    30.36,   30.53,   30.69,   30.86,   31.03,   31.20,   31.37,
    31.55,   31.72,   31.90,   32.07,   32.25,   32.43,   32.62,
    32.80,   32.98,   33.17,   33.36,   33.55,   33.74,   33.93,
    34.13,   34.32,   34.52,   34.72,   34.92,   35.13,   35.33,
    35.54,   35.75,   35.96,   36.17,   36.39,   36.60,   36.82,
    37.04,   37.26,   37.49,   37.71,   37.94,   38.17,   38.40,
    38.64,   38.87,   39.11,   39.35, ),
( 18.12,   18.20,   18.27,   18.35,   18.43,   18.51,   18.59,
    18.66,   18.74,   18.82,   18.90,   18.98,   19.07,   19.15,
    19.23,   19.31,   19.40,   19.48,   19.57,   19.65,   19.74,
    19.82,   19.91,   20.00,   20.08,   20.17,   20.26,   20.35,
    20.44,   20.53,   20.63,   20.72,   20.81,   20.90,   21.00,
    21.09,   21.19,   21.28,   21.38,   21.48,   21.92,   23.20,
    26.08,   30.44,   34.20,   37.77,   39.88,   41.80,   43.22,
    44.84,   46.62,   49.78,   62.76,   83.22,   84.50,   84.77,
    85.04,   84.23,   79.52,   76.60,   73.22,   70.57,   66.47,
    73.35,   95.00,  103.07,   95.34,   95.00,   95.42,   95.00,
    95.64,   96.91,   98.65,   98.15,   99.21,   98.99,   97.74,
    96.15,   95.78,   95.71,   96.43,   95.03,   95.43,   86.37,
    69.64,   69.94,   72.52,   78.63,   81.15,   84.55,   79.63,
    77.67,   74.59,   70.07,   66.99,   51.62,   46.38,   44.69,
    41.42,   34.16,   30.60,   29.08,   29.24,   29.39,   29.55,
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    30.85,   31.01,   31.18,   31.35,   31.53,   31.70,   31.87,
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    34.68,   34.88,   35.09,   35.29,   35.50,   35.70,   35.91,
    36.12,   36.34,   36.55,   36.77,   36.99,   37.21,   37.43,
    37.65,   37.88,   38.11,   38.34, ),
( 17.72,   17.79,   17.87,   17.94,   18.01,   18.09,   18.16,
    18.24,   18.32,   18.39,   18.47,   18.55,   18.63,   18.70,
    18.78,   18.86,   18.94,   19.02,   19.11,   19.19,   19.27,
    19.35,   19.44,   19.52,   19.60,   19.69,   19.77,   19.86,
    19.95,   20.03,   20.12,   20.21,   20.30,   20.39,   20.48,
    20.57,   20.66,   20.75,   20.85,   20.94,   21.03,   21.13,
    22.36,   24.26,   28.66,   32.72,   36.34,   38.91,   41.06,
    42.50,   44.03,   45.82,   51.86,   80.26,   82.58,   84.40,
    84.66,   84.93,   79.90,   76.93,   73.46,   70.86,   77.10,
    95.00,  100.31,  101.05,   96.70,   95.07,   95.00,   95.45,
    96.02,   97.65,   99.59,   99.21,   99.24,   99.20,   98.08,
    96.54,   95.94,   95.60,   96.15,   95.00,   95.00,   99.34,
    89.27,   69.20,   73.04,   79.13,   80.35,   84.02,   76.16,
    72.91,   68.43,   65.63,   58.15,   44.88,   43.40,   39.57,
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    28.75,   28.90,   29.05,   29.20,   29.35,   29.50,   29.66,
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    32.14,   32.31,   32.49,   32.67,   32.85,   33.03,   33.22,
    33.40,   33.59,   33.78,   33.97,   34.16,   34.35,   34.55,
    34.74,   34.94,   35.14,   35.34,   35.54,   35.75,   35.96,
    36.16,   36.37,   36.59,   36.80, ),
( 17.18,   17.25,   17.32,   17.39,   17.46,   17.53,   17.60,
    17.67,   17.74,   17.82,   17.89,   17.96,   18.03,   18.11,
    18.18,   18.26,   18.33,   18.41,   18.48,   18.56,   18.64,
    18.72,   18.79,   18.87,   18.95,   19.03,   19.11,   19.19,
    19.27,   19.36,   19.44,   19.52,   19.60,   19.69,   19.77,
    19.86,   19.94,   20.03,   20.11,   20.20,   20.29,   20.38,
    20.47,   21.30,   22.61,   26.63,   30.99,   34.64,   37.71,
    39.87,   41.54,   42.99,   44.78,   71.48,   78.94,   81.69,
    83.83,   84.31,   80.45,   76.94,   73.58,   85.19,   95.58,
    95.12,  100.55,   99.06,   97.34,   95.36,   95.00,   95.32,
    96.35,   98.65,   99.36,   98.98,   98.73,   98.63,   97.01,
    97.10,   96.14,   95.41,   95.80,   95.00,   95.00,   97.73,
    98.49,   93.26,   76.75,   78.20,   79.53,   80.67,   70.91,
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    27.49,   26.57,   26.70,   26.83,   26.96,   27.09,   27.22,
    27.35,   27.49,   27.62,   27.76,   27.89,   28.03,   28.17,
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    29.32,   29.46,   29.61,   29.76,   29.92,   30.07,   30.22,
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    33.92,   34.11,   34.29,   34.48, ),
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    17.38,   17.44,   17.51,   17.58,   17.65,   17.72,   17.79,
    17.86,   17.93,   18.00,   18.07,   18.14,   18.21,   18.28,
    18.36,   18.43,   18.50,   18.58,   18.65,   18.73,   18.80,
    18.88,   18.95,   19.03,   19.11,   19.19,   19.26,   19.34,
    19.42,   19.50,   19.93,   21.24,   24.26,   28.76,   32.60,
    36.18,   38.34,   40.25,   41.70,   61.45,   73.78,   77.27,
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    95.00,  100.68,   96.38,   97.76,   95.62,   95.26,   95.00,
    96.36,   98.46,   98.25,   97.39,   97.21,   97.73,   96.13,
    95.96,   96.06,   95.32,   95.00,   95.00,   95.21,   96.26,
    96.56,   99.73,  101.24,   82.40,   77.64,   73.64,   64.14,
    61.88,   59.21,   53.64,   39.74,   34.82,   28.56,   25.39,
    24.76,   24.88,   24.99,   25.11,   25.23,   25.35,   25.46,
    25.58,   25.70,   25.83,   25.95,   26.07,   26.19,   26.32,
    26.44,   26.57,   26.70,   26.83,   26.96,   27.09,   27.22,
    27.35,   27.48,   27.62,   27.75,   27.89,   28.02,   28.16,
    28.30,   28.44,   28.58,   28.72,   28.86,   29.01,   29.15,
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    16.04,   16.10,   16.16,   16.22,   16.28,   16.34,   16.40,
    16.47,   16.53,   16.59,   16.65,   16.72,   16.78,   16.84,
    16.91,   16.97,   17.04,   17.10,   17.17,   17.24,   17.30,
    17.37,   17.44,   17.50,   17.57,   17.64,   17.71,   17.78,
    17.85,   17.92,   17.99,   18.06,   18.13,   18.20,   18.27,
    18.34,   18.42,   18.49,   18.56,   19.82,   21.82,   26.35,
    30.50,   34.23,   36.78,   38.93,   51.95,   70.68,   72.54,
    75.56,   79.17,   84.70,   98.54,  101.34,   97.77,   95.59,
    95.42,   98.73,   95.00,   98.20,   96.35,   96.22,   95.00,
    95.99,   97.40,   96.51,   95.86,   95.96,   96.28,   95.37,
    95.27,   95.05,   95.16,   95.00,   95.00,   95.63,   96.00,
    95.88,   98.86,  103.60,  103.02,   85.05,   66.18,   60.11,
    57.38,   54.69,   44.87,   32.62,   26.79,   23.65,   23.33,
    23.44,   23.56,   23.67,   23.79,   23.91,   24.03,   24.15,
    24.27,   24.39,   24.52,   24.64,   24.77,   24.89,   25.02,
    25.15,   25.28,   25.41,   25.54,   25.67,   25.80,   25.94,
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    27.05,   27.19,   27.34,   27.49,   27.63,   27.78,   27.93,
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    30.41,   30.60,   30.78,   30.97, ),
(   14.86,   14.92,   14.98,   15.04,   15.10,   15.16,   15.22,
    15.28,   15.34,   15.40,   15.47,   15.53,   15.59,   15.65,
    15.72,   15.78,   15.84,   15.91,   15.97,   16.04,   16.11,
    16.17,   16.24,   16.30,   16.37,   16.44,   16.51,   16.58,
    16.65,   16.72,   16.79,   16.86,   16.93,   17.00,   17.07,
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    24.36,   28.84,   32.60,   35.68,   42.89,   68.41,   69.94,
    71.83,   83.35,  103.52,  102.65,  101.43,   98.19,   96.95,
    95.76,   98.53,   95.00,   99.58,   98.03,   97.35,   95.21,
    95.83,   95.97,   95.56,   95.11,   95.51,   95.89,   95.00,
    95.17,   95.25,   95.00,   95.53,   96.24,   96.94,   96.72,
    96.78,   98.64,  100.23,  100.70,  102.28,   75.74,   56.43,
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    23.02,   23.14,   23.26,   23.39,   23.51,   23.64,   23.77,
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    29.34,   29.54,   29.74,   29.95,   30.15,   30.36,   30.57,
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( 14.54,   14.60,   14.65,   14.71,   14.77,   14.83,   14.88,
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    15.87,   15.94,   16.01,   16.08,   16.16,   16.23,   16.30,
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    16.90,   16.97,   17.05,   17.13,   17.21,   17.29,   17.37,
    17.45,   17.53,   17.61,   17.69,   17.78,   17.86,   18.30,
    19.66,   22.85,   27.51,   31.46,   35.08,   64.11,   68.26,
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    18.39,   19.71,   21.86,   26.59,   30.88,   55.01,   83.05,
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    96.54,   95.07,   95.00,   95.72,   95.00,   96.84,   97.30,
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    96.41,   95.17,   95.00,   95.83,   95.00,   97.12,   98.29,
    97.55,   97.52,   97.76,   98.34,   99.66,   99.55,   97.70,
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   18.60,   18.69,   18.78,   18.88,   18.97,   19.06,   19.16,
   19.25,   19.35,   19.45,   27.52,   45.17,   58.55,   85.96,
   90.42,   94.36,   96.83,   98.11,   95.00,   96.56,   96.65,
  103.29,  100.17,  104.68,  105.00,  104.53,   99.42,   98.79,
   96.03,   95.08,   95.00,   95.32,   95.23,   96.65,   98.91,
   98.32,   98.09,   98.34,   98.05,   98.33,   97.66,   95.19,
   95.92,   95.00,  100.30,   97.75,   92.33,   78.72,   74.24,
   62.18,   57.03,   53.80,   31.14,   24.77,   24.92,   25.07,
   25.22,   25.38,   25.54,   25.69,   25.85,   26.02,   26.18,
   26.34,   26.51,   26.68,   26.84,   27.02,   27.19,   27.36,
   27.59,   27.85,   28.11,   28.38,   28.65,   28.92,   29.19,
   29.47,   29.75,   30.04,   30.33,   30.62,   30.92,   31.22,
   31.52,   31.83,   32.14,   32.45,   32.77,   33.09,   33.42,
   33.75,   34.08,   34.42,   34.76,   35.11,   35.46,   35.82,
   36.18,   36.54,   36.92,   37.33,   37.74,   38.16,   38.59,
   39.02,   39.46,   39.90,   40.35, ),
( 15.46,   15.53,   15.60,   15.67,   15.74,   15.81,   15.88,
   15.95,   16.03,   16.10,   16.17,   16.25,   16.32,   16.40,
   16.47,   16.55,   16.62,   16.70,   16.78,   16.86,   16.94,
   17.01,   17.09,   17.17,   17.25,   17.34,   17.42,   17.50,
   17.58,   17.67,   17.75,   17.84,   17.92,   18.01,   18.10,
   18.18,   18.28,   18.37,   18.47,   18.57,   18.67,   18.77,
   18.87,   18.97,   19.07,   19.17,   19.28,   19.38,   19.48,
   19.59,   19.70,   31.08,   46.95,   46.86,   48.22,   80.14,
   85.60,   90.16,   94.71,   98.03,   96.32,   96.87,   97.82,
  100.34,   98.01,  103.94,  104.72,  105.00,   99.93,   99.66,
   96.55,   95.31,   95.59,   95.00,   95.88,   96.58,   99.97,
   99.52,   98.72,   98.58,   96.89,   96.87,   95.69,   95.00,
   95.73,   97.20,  101.32,   97.89,   86.66,   77.42,   73.56,
   58.58,   58.80,   59.35,   60.13,   37.32,   27.20,   27.45,
   27.69,   27.94,   28.19,   28.45,   28.70,   28.96,   29.23,
   29.49,   29.76,   30.03,   30.31,   30.61,   30.91,   31.22,
   31.54,   31.86,   32.18,   32.51,   32.84,   33.17,   33.51,
   33.86,   34.20,   34.56,   34.91,   35.27,   35.64,   36.01,
   36.38,   36.76,   37.14,   37.53,   37.92,   38.32,   38.72,
   39.13,   39.54,   39.96,   40.39,   40.75,   41.04,   41.34,
   41.64,   41.94,   42.25,   42.56,   42.87,   43.19,   43.50,
   43.83,   44.15,   44.48,   44.81, ),
( 15.65,   15.73,   15.80,   15.88,   15.96,   16.04,   16.12,
   16.20,   16.28,   16.36,   16.44,   16.52,   16.60,   16.69,
   16.77,   16.85,   16.94,   17.02,   17.11,   17.20,   17.29,
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    17.37,   17.46,   17.55,   17.64,   17.73,   17.82,   17.92,
    18.01,   18.10,   18.20,   18.29,   18.39,   18.49,   18.58,
    18.68,   18.78,   18.88,   18.98,   19.10,   19.25,   19.40,
    19.55,   19.71,   19.86,   20.02,   20.18,   20.34,   20.50,
    20.66,   35.70,   47.79,   47.76,   48.04,   48.56,   72.17,
    81.17,   86.43,   92.12,   97.40,   98.82,   98.11,  100.77,
   100.20,   97.85,  102.79,  104.74,  105.00,  102.67,  101.66,
    99.28,   97.84,   97.69,   97.25,   98.67,   99.15,  102.73,
   102.41,  101.02,   98.92,   96.53,   96.31,   98.05,   96.95,
    96.50,  103.39,  101.56,   95.00,   87.12,   80.49,   72.09,
    63.38,   62.88,   63.00,   63.51,   64.45,   45.36,   31.37,
    31.67,   31.98,   32.28,   32.60,   32.91,   33.23,   33.55,
    33.88,   34.18,   34.41,   34.63,   34.86,   35.10,   35.33,
    35.57,   35.80,   36.04,   36.29,   36.53,   36.78,   37.03,
    37.28,   37.54,   37.80,   38.06,   38.32,   38.59,   38.86,
    39.13,   39.40,   39.68,   39.96,   40.24,   40.53,   40.81,
    41.24,   41.68,   42.14,   42.60,   43.06,   43.54,   44.02,
    44.50,   44.99,   45.49,   45.99,   46.50,   47.02,   47.55,
    48.08,   48.62,   49.16,   49.71, ),
(   16.05,   16.13,   16.21,   16.31,   16.43,   16.55,   16.67,
    16.79,   16.91,   17.04,   17.16,   17.29,   17.41,   17.54,
    17.67,   17.80,   17.93,   18.07,   18.20,   18.33,   18.47,
    18.61,   18.75,   18.89,   19.03,   19.17,   19.32,   19.46,
    19.61,   19.76,   19.91,   20.06,   20.21,   20.37,   20.52,
    20.68,   20.84,   21.00,   21.16,   21.32,   21.49,   21.66,
    21.83,   22.01,   22.20,   22.39,   22.58,   22.78,   25.73,
    41.57,   49.92,   49.92,   50.36,   50.88,   51.19,   67.26,
    82.64,   85.20,   90.03,   96.48,  100.72,   98.88,  104.15,
   101.22,  100.38,  103.41,  103.65,  104.07,  104.38,  104.52,
   102.83,  101.16,  100.51,  100.51,  101.89,  102.68,  104.93,
   105.00,  101.76,   98.46,   95.31,   98.83,  100.19,   98.29,
    99.97,  104.66,   98.64,   95.04,   87.86,   85.11,   69.84,
    67.00,   66.47,   65.89,   65.78,   66.11,   66.98,   51.65,
    33.57,   33.79,   34.01,   34.23,   34.46,   34.68,   34.96,
    35.31,   35.67,   36.02,   36.39,   36.76,   37.13,   37.50,
    37.89,   38.27,   38.66,   39.06,   39.46,   39.86,   40.27,
    40.69,   41.11,   41.53,   41.96,   42.40,   42.84,   43.28,
    43.74,   44.19,   44.66,   45.01,   45.31,   45.62,   45.92,
    46.23,   46.54,   46.86,   47.18,   47.50,   47.82,   48.15,
    48.48,   48.82,   49.16,   49.50,   49.85,   50.19,   50.55,
    50.90,   51.26,   51.63,   51.99, ),
(   17.69,   17.81,   17.94,   18.07,   18.20,   18.33,   18.46,
    18.59,   18.72,   18.87,   19.02,   19.17,   19.32,   19.47,
    19.63,   19.78,   19.94,   20.10,   20.26,   20.42,   20.58,
    20.75,   20.92,   21.08,   21.25,   21.43,   21.60,   21.77,
    21.95,   22.13,   22.31,   22.49,   22.68,   22.86,   23.05,
    23.24,   23.43,   23.62,   23.82,   24.01,   24.21,   24.41,
    24.62,   24.82,   25.03,   25.18,   25.33,   31.82,   47.48,
    52.07,   52.03,   52.52,   52.93,   53.18,   53.66,   62.90,
    85.57,   86.89,   89.65,   93.60,   98.74,   97.31,  105.00,
   100.80,  102.38,  103.39,  102.68,   99.85,  102.33,  102.59,
   103.79,  102.85,  101.15,  101.60,  102.54,  102.95,  103.86,
   103.39,   99.48,   95.66,   95.00,   99.08,  100.67,   99.85,
   100.62,  100.88,   98.04,   96.87,   89.95,   82.88,   72.20,
    71.39,   70.53,   70.13,   69.68,   69.56,   69.96,   70.94,
    59.69,   37.66,   38.02,   38.39,   38.72,   38.96,   39.20,
    39.44,   39.69,   39.94,   40.19,   40.44,   40.70,   40.96,
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    41.22,   41.48,   41.74,   42.01,   42.28,   42.55,   42.83,
    43.11,   43.39,   43.67,   43.96,   44.25,   44.54,   44.83,
    45.19,   45.54,   45.91,   46.27,   46.64,   47.02,   47.40,
    47.78,   48.17,   48.56,   48.95,   49.35,   49.76,   50.17,
    50.58,   51.00,   51.42,   51.85,   52.29,   52.73,   53.12,
    53.44,   53.77,   54.10,   54.43, ),
283 (  19.70,   19.85,   20.00,   20.15,   20.31,   20.46,   20.62,
    20.78,   20.94,   21.10,   21.27,   21.43,   21.60,   21.77,
    21.90,   22.02,   22.14,   22.25,   22.37,   22.49,   22.61,
    22.73,   22.85,   22.98,   23.10,   23.22,   23.35,   23.48,
    23.60,   23.73,   23.86,   23.99,   24.12,   24.26,   24.39,
    24.53,   24.66,   24.80,   24.94,   25.08,   25.22,   25.36,
    25.50,   25.64,   25.79,   25.94,   35.95,   51.53,   52.58,
    52.74,   53.31,   53.75,   54.09,   54.73,   55.55,   58.38,
    88.48,   90.01,   91.04,   94.02,   95.00,   95.66,  102.09,
   100.70,  104.28,  104.10,  103.48,   99.57,  100.72,  100.31,
   104.28,  105.00,  104.44,  105.00,  104.94,  105.00,  103.68,
   102.88,   99.28,   97.08,   96.51,  100.78,  103.82,   98.86,
   100.75,  101.16,  100.46,   99.70,   92.00,   79.71,   74.88,
    74.96,   74.29,   73.17,   72.66,   72.10,   71.70,   71.98,
    72.74,   65.41,   41.34,   39.34,   39.63,   39.93,   40.22,
    40.52,   40.83,   41.13,   41.44,   41.76,   42.07,   42.39,
    42.71,   43.04,   43.37,   43.70,   44.04,   44.38,   44.72,
    45.07,   45.42,   45.78,   46.14,   46.40,   46.67,   46.93,
    47.20,   47.47,   47.75,   48.02,   48.30,   48.58,   48.87,
    49.15,   49.44,   49.73,   50.02,   50.32,   50.62,   50.92,
    51.22,   51.53,   51.84,   52.15,   52.47,   52.78,   53.10,
    53.43,   53.75,   54.08,   54.42, ),
284 (  20.94,   21.04,   21.15,   21.26,   21.37,   21.48,   21.59,
    21.71,   21.82,   21.93,   22.05,   22.16,   22.28,   22.40,
    22.52,   22.63,   22.76,   22.88,   23.01,   23.19,   23.38,
    23.57,   23.77,   23.96,   24.16,   24.36,   24.56,   24.76,
    24.96,   25.17,   25.38,   25.59,   25.80,   26.01,   26.23,
    26.45,   26.67,   26.89,   27.12,   27.35,   27.58,   27.81,
    28.04,   28.28,   28.52,   42.08,   55.04,   55.10,   55.39,
    55.91,   56.23,   56.51,   57.12,   57.97,   59.19,   60.53,
    86.79,   93.14,   93.78,   96.16,   95.00,   95.00,   97.74,
    98.65,  103.70,  102.92,  102.87,   98.99,   99.40,   96.80,
   100.91,  102.99,  103.75,  105.00,  103.76,  102.35,   99.63,
    99.70,   98.16,   95.49,   96.77,  102.06,   99.71,   97.92,
    99.27,  101.71,  102.15,  100.87,   90.30,   77.05,   77.22,
    76.94,   77.02,   76.65,   75.49,   74.98,   74.48,   73.98,
    74.32,   75.00,   71.77,   47.43,   41.32,   41.55,   41.77,
    42.00,   42.22,   42.45,   42.68,   42.92,   43.15,   43.39,
    43.63,   43.87,   44.11,   44.36,   44.60,   44.85,   45.10,
    45.36,   45.61,   45.87,   46.13,   46.39,   46.66,   46.92,
    47.19,   47.46,   47.74,   48.01,   48.29,   48.57,   48.85,
    49.14,   49.43,   49.72,   50.01,   50.31,   50.60,   48.48,
    45.86,   43.19,   40.46,   37.69,   34.86,   31.98,   29.05,
    26.05,   23.01,   19.90,   16.74, ),
285 (  22.10,   22.27,   22.45,   22.62,   22.80,   22.98,   23.16,
    23.34,   23.52,   23.71,   23.89,   24.08,   24.27,   24.46,
    24.66,   24.85,   25.05,   25.25,   25.45,   25.65,   25.86,
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    27.07,   27.21,   27.35,   27.49,   27.63,   27.78,   27.92,
    28.07,   28.22,   28.36,   28.51,   28.66,   28.82,   28.97,
    29.12,   31.02,   46.14,   55.40,   55.37,   55.69,   56.18,
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```
    56.45,   56.80,   57.45,   58.44,   59.68,   61.09,   62.36,
    81.03,   94.33,   95.26,   96.72,   95.42,   96.97,   95.05,
    95.00,  100.12,   99.91,  100.47,   98.10,   97.77,   95.99,
    98.44,   99.22,  101.25,  102.18,  102.21,   99.28,   97.32,
    98.65,   97.06,   95.00,   98.77,   99.08,   95.98,   99.83,
   100.39,  102.59,  103.41,  101.38,   85.25,   78.08,   78.27,
    78.51,   78.16,   78.08,   77.88,   76.63,   75.90,   75.33,
    74.71,   74.85,   75.38,   76.29,   51.77,   41.54,   41.76,
    41.99,   42.21,   42.44,   42.67,   42.91,   43.14,   43.38,
    43.62,   43.86,   44.10,   44.35,   44.59,   44.84,   42.95,
    40.76,   38.54,   36.27,   33.97,   31.62,   29.24,   26.81,
    24.33,   21.82,   19.25,   16.65,   13.99,   11.29,    8.54,
     5.75,    2.90,    0.00,    0.00,    0.00,    0.00,    0.00,
     0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
     0.00,    0.00,    0.00,    0.00, ),
( 23.94,   24.06,   24.18,   24.30,   24.41,   24.53,   24.65,
    24.78,   24.90,   25.02,   25.15,   25.27,   25.40,   25.52,
    25.65,   25.78,   25.91,   26.04,   26.17,   26.30,   26.44,
    26.57,   26.71,   26.84,   26.98,   27.12,   27.29,   27.46,
    27.62,   27.80,   27.97,   28.14,   28.32,   28.49,   28.67,
    28.85,   29.03,   29.22,   29.40,   29.59,   29.77,   29.96,
    35.34,   50.37,   56.12,   56.12,   56.60,   57.08,   57.37,
    57.84,   58.49,   59.60,   60.83,   62.18,   63.29,   64.09,
    75.08,   95.46,   97.10,   96.99,   96.39,  100.64,   95.08,
    95.00,   95.00,   95.00,   95.00,   95.00,   95.00,   95.00,
    95.00,   95.94,   95.00,   95.00,   95.00,   95.00,   95.00,
    95.00,   95.00,   95.00,   95.00,   95.00,   95.00,  102.08,
   100.90,  102.47,  103.55,  100.58,   79.31,   78.66,   78.65,
    78.77,   79.11,   78.80,   78.63,   78.69,   77.43,   74.63,
    72.01,   69.30,   67.16,   65.43,   64.16,   41.46,   24.76,
    22.69,   20.59,   18.45,   16.27,   14.06,   11.82,    9.53,
     7.21,    4.84,    2.44,    0.00,    0.00,    0.00,    0.00,
     0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
     0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
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     0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
     0.00,    0.00,    0.00,    0.00, ),
( 24.34,   24.48,   24.63,   24.77,   24.91,   25.06,   25.21,
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    26.43,   26.59,   26.75,   26.91,   27.07,   27.24,   27.40,
    27.57,   27.74,   27.91,   28.08,   28.25,   28.43,   28.60,
    28.78,   28.90,   29.03,   29.16,   29.30,   29.43,   29.56,
    29.70,   29.83,   29.97,   30.11,   30.24,   30.38,   39.09,
    53.94,   56.15,   56.17,   56.64,   57.01,   57.25,   57.73,
    58.32,   59.48,   60.70,   62.04,   63.03,   63.82,   64.10,
    67.67,   95.51,   97.93,   96.28,   97.25,  103.01,   95.68,
    96.36,   93.93,   90.13,   87.85,   89.47,   90.24,   92.15,
    90.60,   91.54,   89.71,   86.44,   87.34,   89.56,   88.60,
    89.05,   87.77,   82.98,   84.26,   82.04,   85.80,   87.83,
    85.38,   84.16,   83.03,   70.62,   54.71,   52.46,   50.50,
    48.38,   46.23,   44.36,   41.94,   39.39,   39.25,   38.02,
    36.78,   36.00,   35.15,   34.74,   34.85,   35.55,   18.99,
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     0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
     0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
     0.00,    0.00,    0.00,    0.00,    0.00,    0.00,    0.00,
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    0.00,   0.00,   0.00,   0.00,   0.00,   0.00,   0.00,
    0.00,   0.00,   0.00,   0.00, ),
288 (  25.30,  25.45,  25.60,  25.75,  25.90,  26.03,  26.14,
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    27.05,  27.17,  27.29,  27.41,  27.53,  27.65,  27.77,
    27.89,  28.01,  28.14,  28.26,  28.39,  28.51,  28.64,
    28.77,  28.90,  29.03,  29.16,  29.29,  29.42,  29.56,
    29.69,  29.83,  29.96,  30.10,  30.24,  42.26,  55.82,
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    59.32,  60.56,  61.89,  62.77,  63.47,  63.65,  62.44,
    61.22,  88.00,  91.45,  88.52,  89.47,  93.06,  85.13,
    83.66,  78.37,  71.43,  63.11,  61.77,  60.87,  61.87,
    57.62,  57.16,  53.49,  49.74,  47.23,  45.49,  48.59,
    51.39,  50.26,  51.19,  56.33,  56.59,  64.64,  65.19,
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    27.05,  27.16,  27.28,  27.40,  27.52,  27.64,  27.76,
    27.89,  28.01,  28.13,  28.26,  28.38,  28.51,  28.64,
    28.76,  28.89,  29.02,  29.15,  29.28,  29.28,  28.14,
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    66.84,   61.69,   53.87,   45.15,   38.91,   32.89,   26.51,
    23.11,   22.49,   27.27,   30.70,   30.08,   26.23,   25.69,
    27.54,   37.16,   46.50,   56.03,   64.66,   65.73,   66.53,
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```

```
      0.00,    0.00,    0.00,    0.00, ),
319 (  0.00,    1.13,   11.65,   20.46,   20.33,   20.28,   20.51,
      20.69,   20.76,   20.93,   21.24,   21.77,   22.50,   23.32,
      24.17,   24.72,   25.18,   25.29,   25.37,   25.46,   25.54,
      25.62,   25.70,   25.78,   25.87,   25.95,   26.03,   26.12,
      26.20,   26.29,   26.37,   26.46,   26.54,   26.22,   25.71,
      24.03,   22.07,   19.35,   17.21,   15.79,   14.02,   12.12,
      11.30,    9.40,    5.05,    2.14,    0.14,    1.76,    0.69,
       0.00,    0.00,    1.93,    5.54,    6.18,    9.92,   10.20,
       6.70,    6.75,    5.16,    2.72,    0.57,    0.00,    0.00,
       0.00,   22.36,   36.93,   38.14,   42.82,   46.30,   44.32,
      44.53,   39.41,   34.03,   31.30,   12.83,   10.30,    4.65,
       4.62,    4.80,    5.80,    7.83,    9.02,    9.35,    5.41,
       3.91,    3.92,    3.92,    4.43,    4.86,    2.54,    1.77,
       1.09,    0.33,    0.02,    0.00,    0.00,    0.00,    0.00,
       0.47,    0.72,    0.50,    0.00,    0.00,    0.00,    0.00,
       0.00,    0.00,    1.31,    4.51,   12.68,   19.73,   25.47,
      29.34,   31.93,   34.84,   38.60,   44.98,   49.26,   51.49,
      51.73,   51.97,   52.22,   52.47,   52.72,   52.97,   53.22,
      53.47,   53.73,   53.98,   53.97,   53.74,   53.53,   53.75,
      52.87,   52.46,   51.26,   49.19,   47.99,   46.68,   46.40,
      46.99,   36.40,    0.00,    0.00,    0.00,    0.00,    0.00,
       0.00,    0.00,    0.00,    0.00, ),
320 (  3.56,   14.01,   20.30,   20.16,   20.20,   20.43,   20.57,
      20.64,   20.86,   21.17,   21.78,   22.50,   23.33,   24.18,
      24.65,   25.06,   25.14,   25.22,   25.30,   25.39,   25.47,
      25.55,   25.63,   25.71,   25.79,   25.88,   25.96,   26.04,
      26.13,   26.21,   26.30,   26.38,   25.99,   25.42,   23.66,
      21.61,   18.91,   16.93,   15.53,   13.73,   11.96,   11.14,
       8.92,    4.61,    1.95,    0.00,    0.00,    2.72,    0.00,
       0.00,    0.58,    3.37,    5.87,    6.22,   11.07,    8.69,
       6.35,    6.66,    4.16,    2.33,    0.15,    0.00,    0.00,
       0.00,   12.80,   37.14,   40.00,   45.29,   47.41,   50.17,
      46.01,   40.51,   35.77,   28.41,    9.77,   10.81,    6.03,
       4.60,    4.83,    6.05,    7.49,    8.53,    8.64,    4.46,
       4.35,    3.93,    3.94,    4.18,    4.88,    3.10,    1.67,
       1.33,    0.60,    0.04,    0.00,    0.00,    0.00,    0.00,
       0.25,    0.71,    0.71,    0.14,    0.00,    0.00,    0.00,
       0.00,    0.00,    0.00,    0.57,    2.87,   10.12,   17.78,
      24.50,   28.41,   31.47,   34.21,   37.48,   43.55,   48.66,
      51.92,   52.17,   52.42,   52.67,   52.92,   53.17,   53.42,
      53.68,   53.93,   54.19,   54.45,   54.51,   54.35,   54.01,
      54.23,   53.57,   53.02,   52.22,   49.91,   48.69,   47.38,
      46.84,   47.26,   43.36,    3.44,    0.00,    0.00,    0.00,
       0.00,    0.00,    0.00,    0.00, ),
321 (  16.32,   20.14,   20.00,   20.12,   20.35,   20.45,   20.52,
      20.79,   21.10,   21.78,   22.51,   23.34,   24.13,   24.57,
      24.92,   25.00,   25.08,   25.16,   25.24,   25.32,   25.40,
      25.48,   25.56,   25.64,   25.72,   25.81,   25.89,   25.97,
      26.05,   26.14,   26.22,   25.76,   25.03,   23.29,   21.15,
      18.47,   16.67,   15.28,   13.44,   11.80,   10.99,    8.44,
       4.17,    1.76,    0.00,    0.00,    0.76,    1.70,    0.00,
       0.00,    1.26,    4.83,    6.20,    6.69,   11.89,    7.42,
       6.38,    5.81,    3.80,    1.90,    0.00,    0.00,    0.00,
       0.00,    3.09,   37.62,   42.08,   46.91,   50.71,   53.09,
      47.32,   41.75,   37.53,   19.69,   11.40,   10.82,    7.43,
       4.58,    4.86,    6.29,    7.15,    8.07,    7.44,    3.93,
```

```
     4.83,    3.95,    3.96,    3.96,    4.70,    3.78,    1.51,
     1.56,    0.88,    0.11,    0.01,    0.00,    0.00,    0.00,
     0.03,    0.61,    0.71,    0.35,    0.00,    0.00,    0.00,
     0.00,    0.00,    0.00,    0.00,    0.00,    2.13,    7.50,
    15.78,   22.64,   27.46,   31.00,   33.60,   36.87,   42.08,
    48.04,   51.92,   52.61,   52.86,   53.12,   53.37,   53.62,
    53.88,   54.14,   54.40,   54.66,   54.92,   55.06,   54.96,
    54.59,   54.71,   54.28,   53.59,   53.19,   50.82,   49.40,
    48.09,   47.28,   47.54,   48.65,   10.09,    0.00,    0.00,
     0.00,    0.00,    0.00,    0.00, ),
)


index = range(-25,26)

#Plotting Beamlets and fluence steps
fig = plt.figure(2)
ax = fig.add_subplot(111)
ax.set_axis_off()

ax = fig.add_subplot(241)
plt.bar(index,a10,label='10')
ax.set_title('10')
plt.xlabel('Offset')
plt.ylabel('Exposure')
ax.set_ylim(0,40)
ax.set_xlim(-25,25)

ax = fig.add_subplot(242)
plt.bar(index,a50,label='50')
ax.set_title('50')
plt.xlabel('Offset')
plt.ylabel('Exposure')
ax.set_ylim(0,40)
ax.set_xlim(-25,25)


ax = fig.add_subplot(243)
plt.bar(index,a90,label='90')
ax.set_title('90')
plt.xlabel('Offset')
plt.ylabel('Exposure')
ax.set_ylim(0,40)
ax.set_xlim(-25,25)


ax = fig.add_subplot(244)
plt.bar(index,a130,label='130')
ax.set_title('130')
plt.xlabel('Offset')
plt.ylabel('Exposure')
ax.set_ylim(0,40)
ax.set_xlim(-25,25)

ax = fig.add_subplot(245)
plt.bar(index,a170,label='170')
ax.set_title('170')
```

```
plt.xlabel('Offset')
plt.ylabel('Exposure')
ax.set_ylim(0,40)
ax.set_xlim(-25,25)

ax = fig.add_subplot(246)
plt.bar(index,a200,label='200')
ax.set_title('200')
plt.xlabel('Offset')
plt.ylabel('Exposure')
ax.set_ylim(0,40)
ax.set_xlim(-25,25)

ax = fig.add_subplot(247)
plt.bar(index,a340,label='340')
ax.set_title('340')
plt.xlabel('Offset')
plt.ylabel('Exposure')
ax.set_ylim(0,40)
ax.set_xlim(-25,25)

#Heatmap of results
fig = plt.figure(3)
ax = fig.add_subplot(111,aspect='equal')

'''
xV = []
yV = []
for x,y in voxels:
    xV.append(x)
    yV.append(y)

matrix = np.zeros((len(xV), len(yV)))

for i in range(len(voxels)):
    matrix[voxels[i][0]+53,voxels[i][1]+75] = dose[i]
'''

plt.imshow(Dose, origin='lower', interpolation='none', extent=[-53,
     53, -75, 75])
ax.set_title('Heatmap of results')

plt.show()
```

colorplot_v2.py

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