Intensity modulated beam scanning with multilayer energy filter for conformal proton therapy

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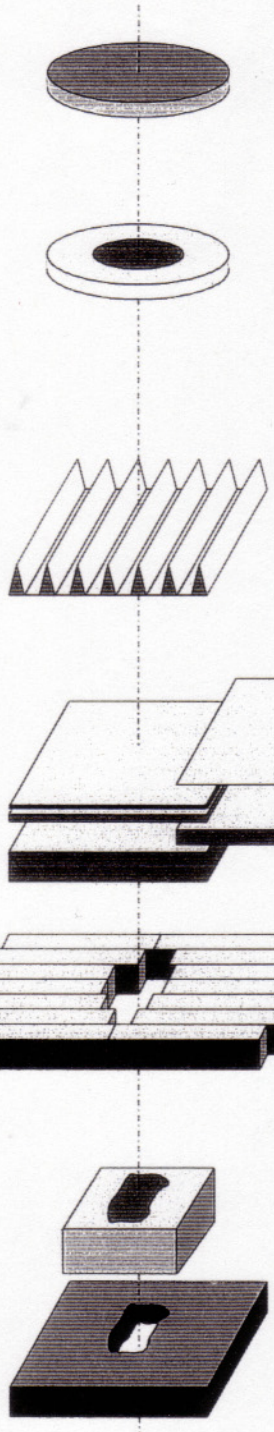
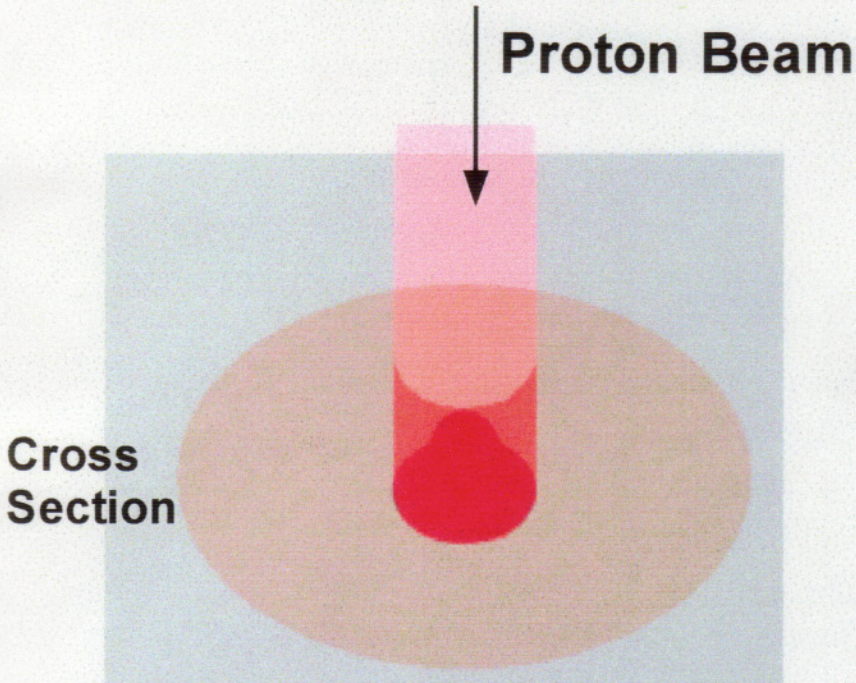
Abstract:
The new filter is made of many layers produced by using stereolithography. It can yield an irradiation field where the width of the spread-out Bragg peak is adjusted to the target.
By using the new filter and two-dimensional beam scanning, a three-dimensional conformal field can be realized. The number of scanning spot can be reduced to the realistic scale in the respiration-gated irradiation technique.

FFAG accelerator has an uncontrollability to make a required dose deposition, because of its dose control scheme without feedback path. The charge which is captured in the injection process of the accelerator can be accelerated and extracted with some efficiency and some fluctuation. One can set the maximum charge for the acceleration but the extracted charge.
To overcome the problem,
Successive approximation technique can be adopted to make a required dose deposition. For the technique, charge modulation of full, a half, 1/4, 1/8, 1/16 and 1/32 should be prepared to make an irradiation with 3% fluctuation of uniformity. The number of the successive dose accumulation will be 5 or 6 for one required dose irradiation. The relative error of the charge modulation should be less than 50% for each modulation.
To realize the successive irradiation, a fast monitor of the intensity for the pulse operation must be installed. The controller should decide the next values of charge in a half msec for all spots making the field.



Beam Delivery System for
Broad Beam Technique

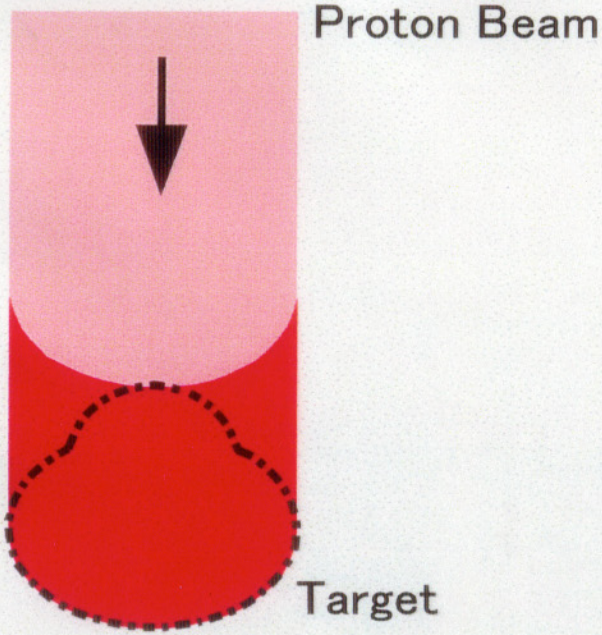
Present Method

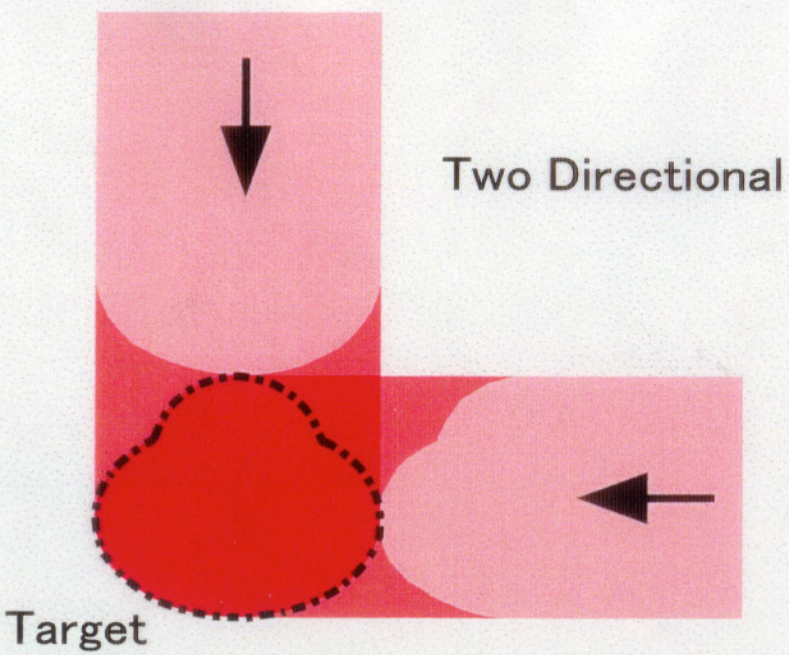


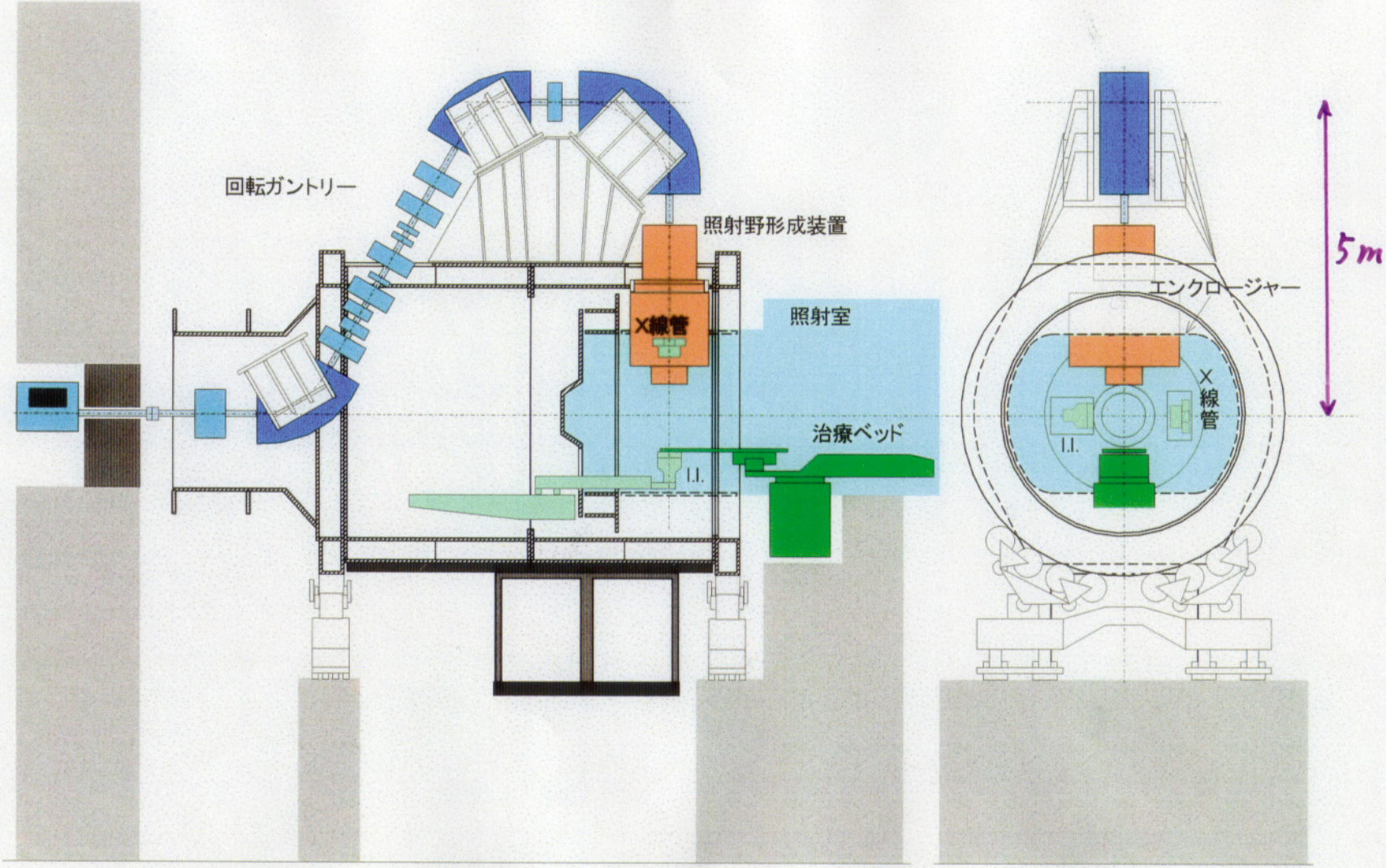
Present Irradiation Technique
(Broad Beam Method with Filters)

+ Gated Irradiation ⇒ Moving Target

To Reduce the normal Tissue Irradiation,







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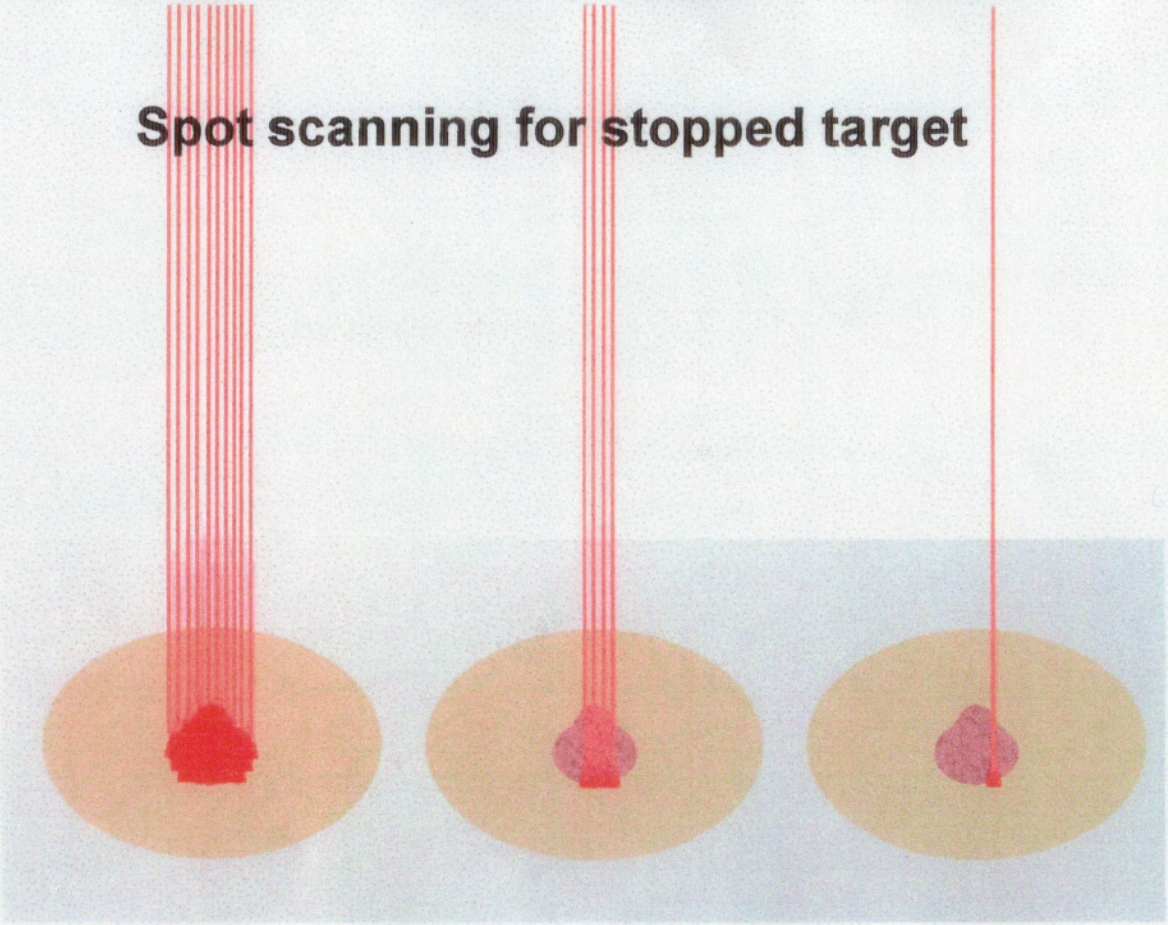
Traditional idea for conformal irradiation

Spot scanning for stopped target



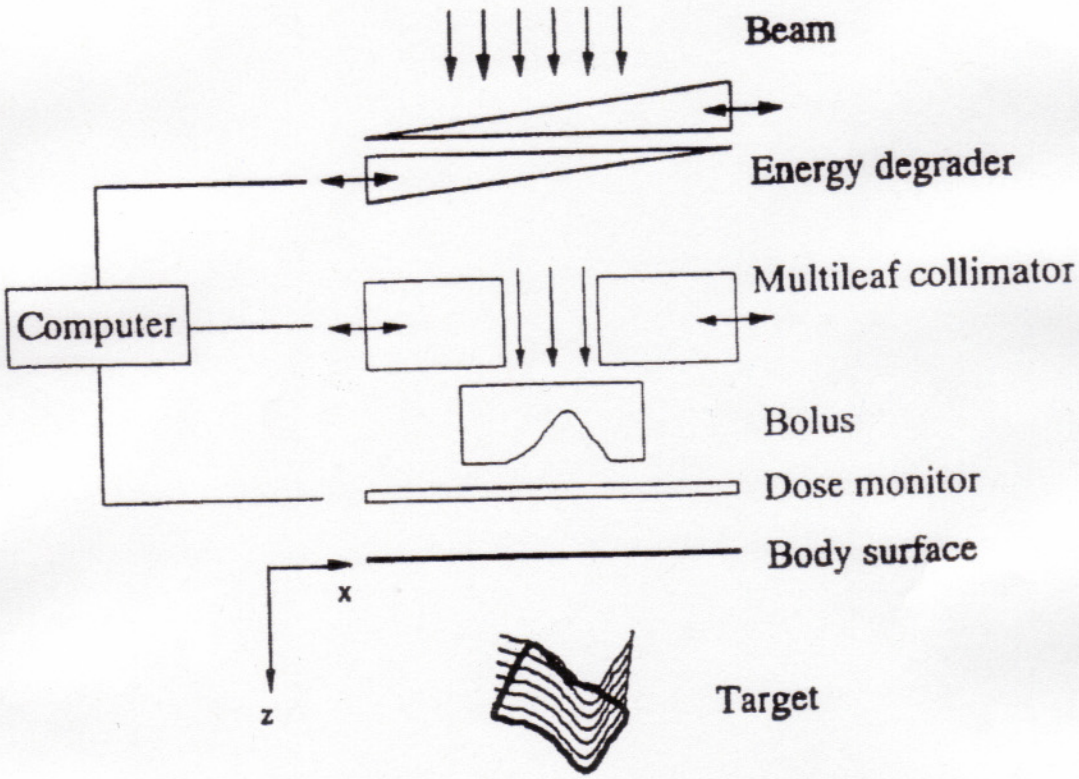
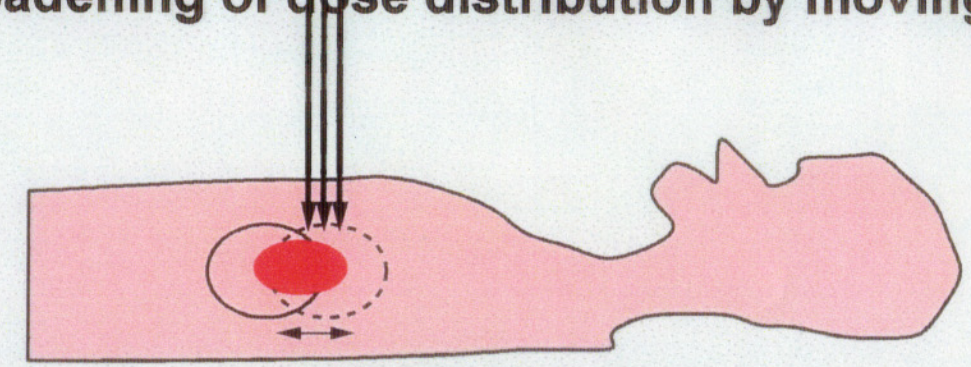


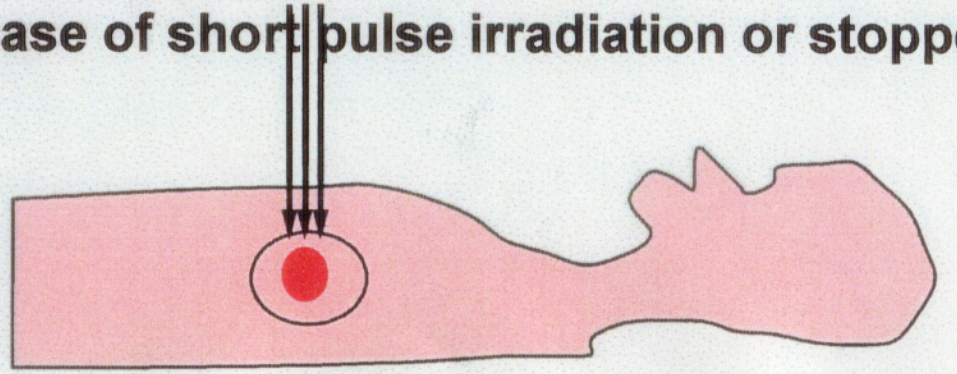
Figure 4. Diagram of the broad beam three-dimensional proton therapy system.

Effect of the respiration moving

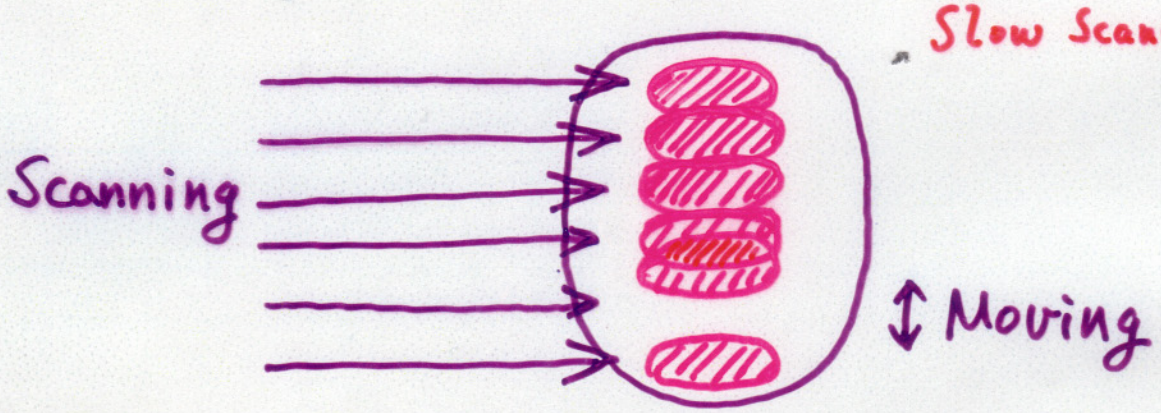
Broadening of dose distribution by moving of target



In case of short pulse irradiation or stopped target



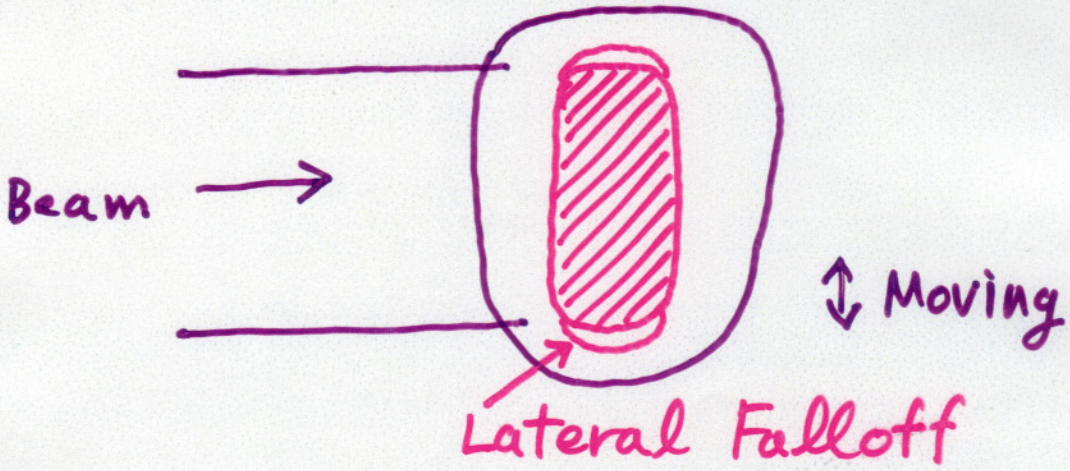
① Conformal Irradiation by Scanning on moving Target.



Max. 5 mm

Gated Irradiation Synchronized with Respiration.

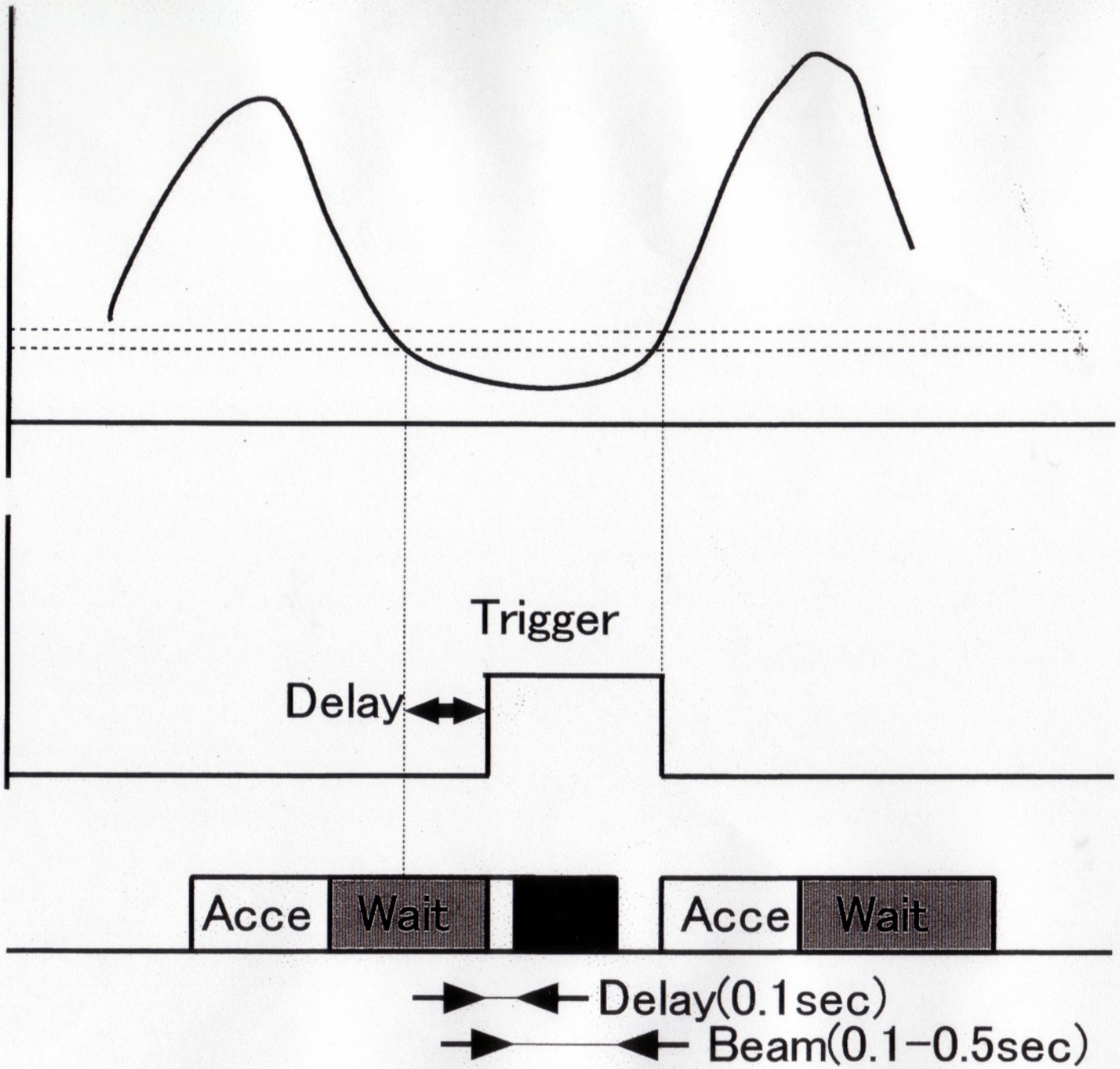
② Static Field Conformed to the Target



To realize the Conformal Irradiation on the moving target,

We need "Static" or "Fast Scanning"

and Depth-directional Spread Control of


Trigger
Delay
Acce
Wait
Acce
Wait
Delay(0.1sec)
Beam(0.1-0.5sec)

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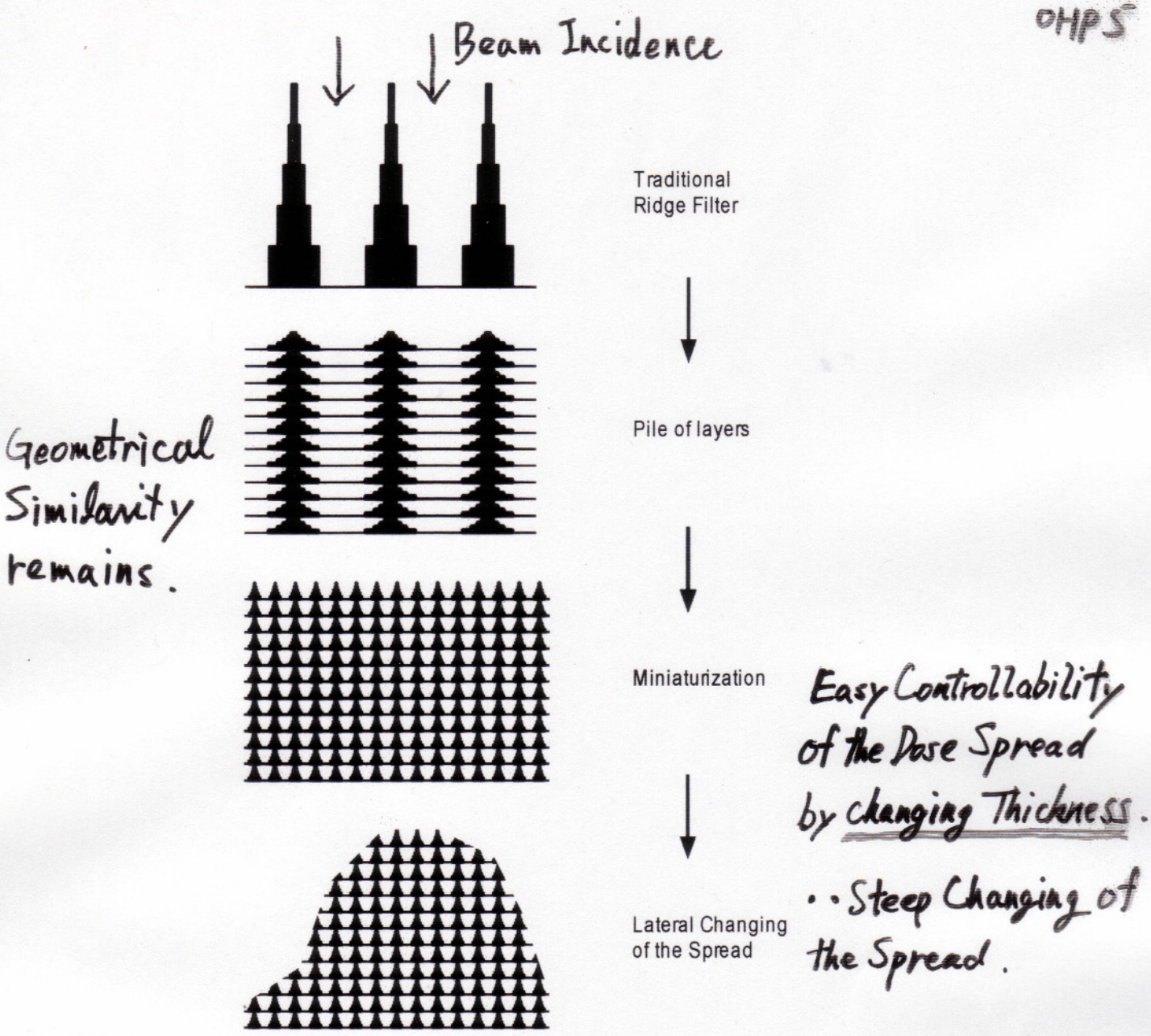

Figure 1. Conceptual changing of the structure and function from the traditional filter to the

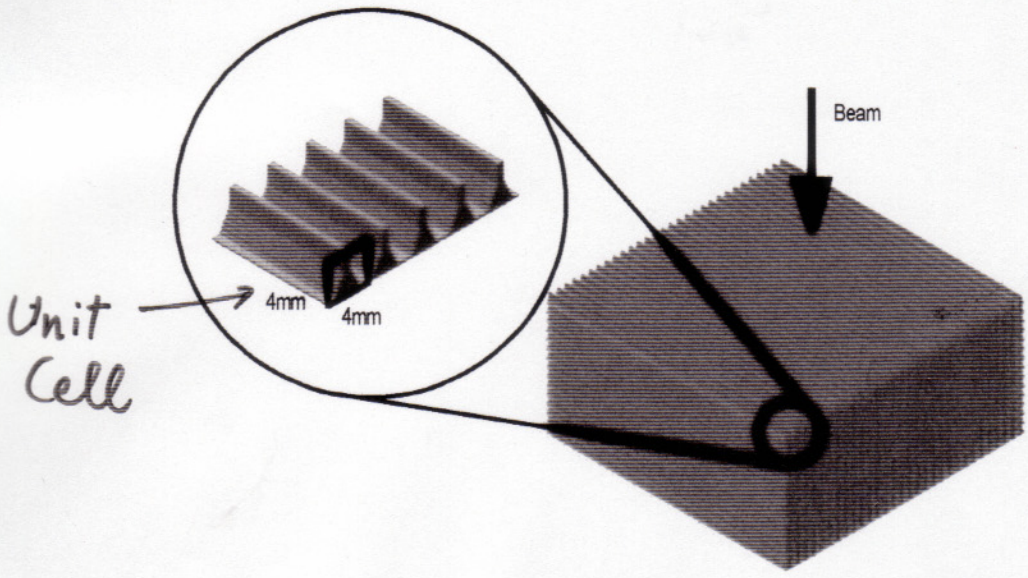

Figure 2. Schematic draws of a block including many layers of ridge-type filt

The new Filter can be Set near the Bolus, or Close to the patient.

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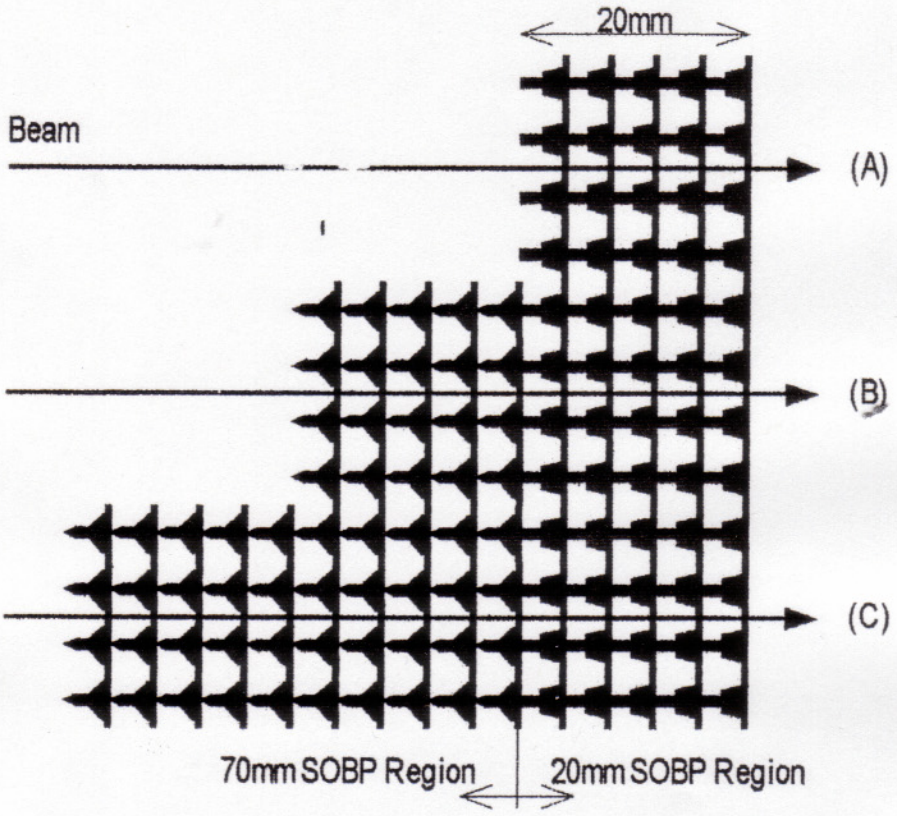
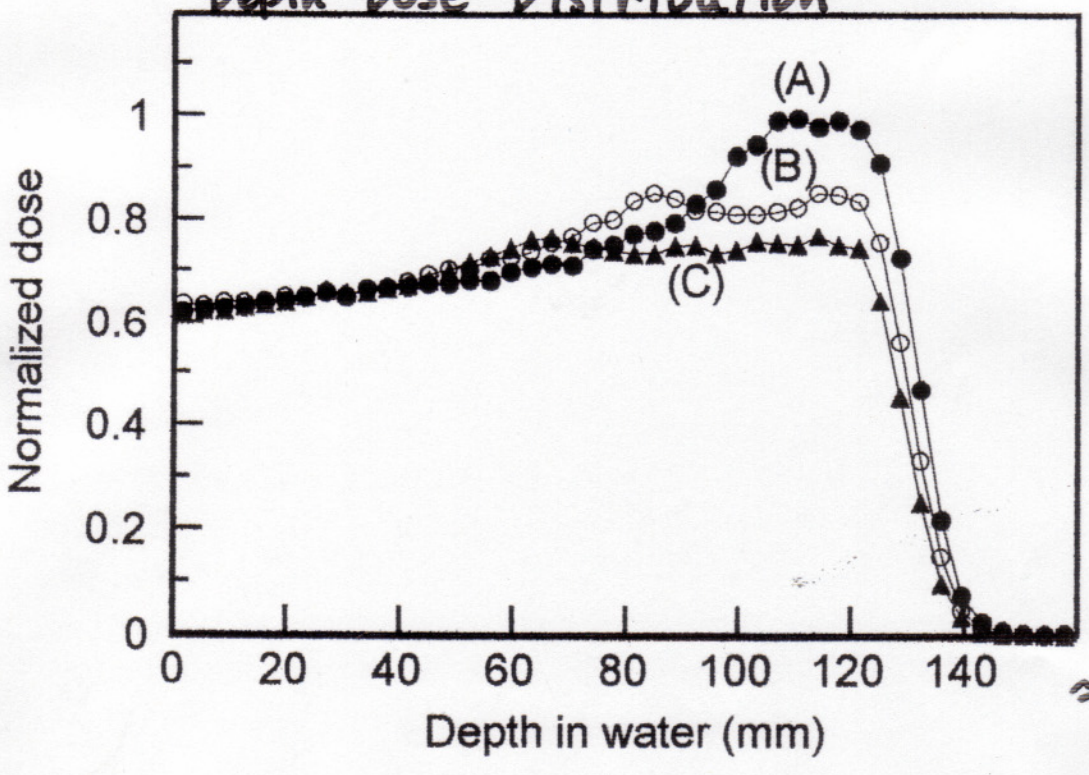
Cross section View of the New Filter with Multi-Region Structure.



Depth Dose Distribution



≈ 150MeV proton

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Experiments for 3-D Dose Distribution

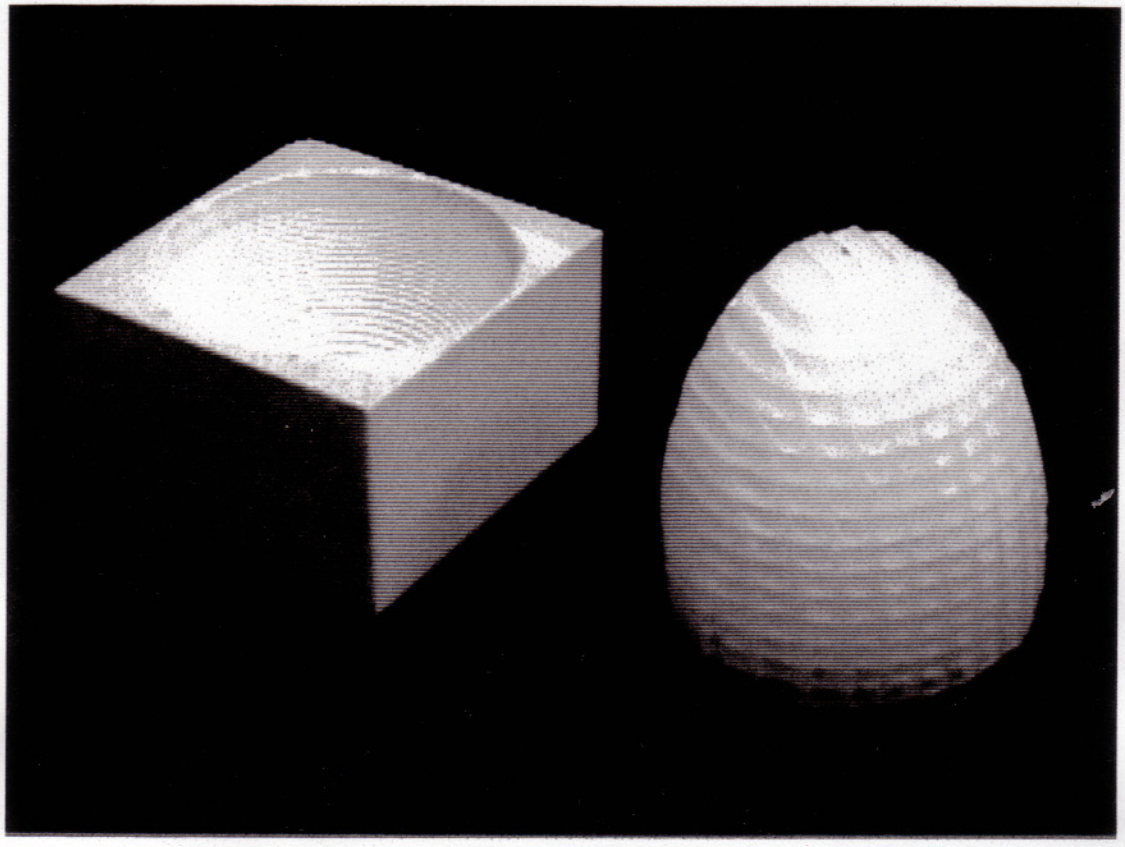
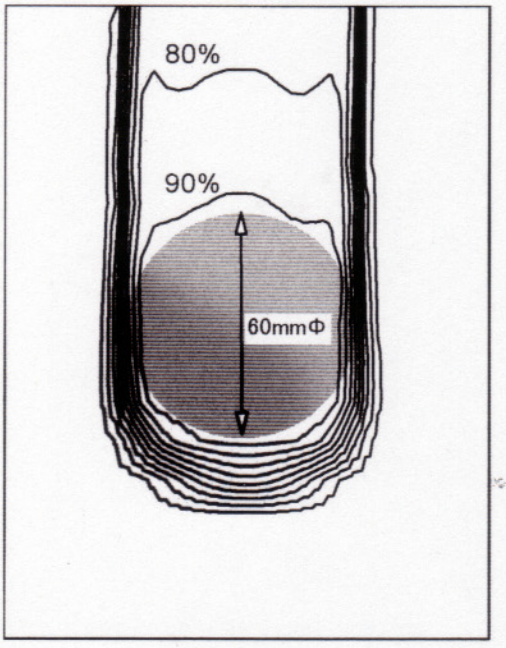
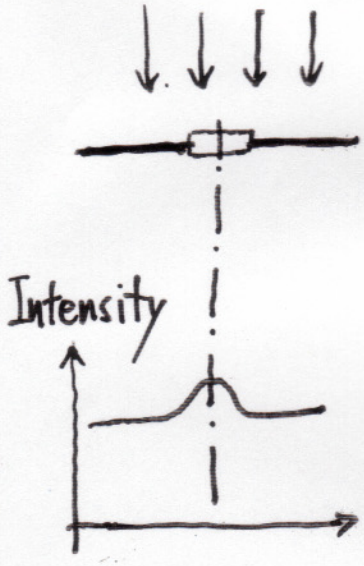


Figure 3, Picture of a set of the bolus and the new filter for the sphere target.

in uniform medium.





Intencity Modulation

Figure 4. Experimental result of the conformal dose distribution on a plane along the beam axis

We can get almost conformal distribution by the new filter

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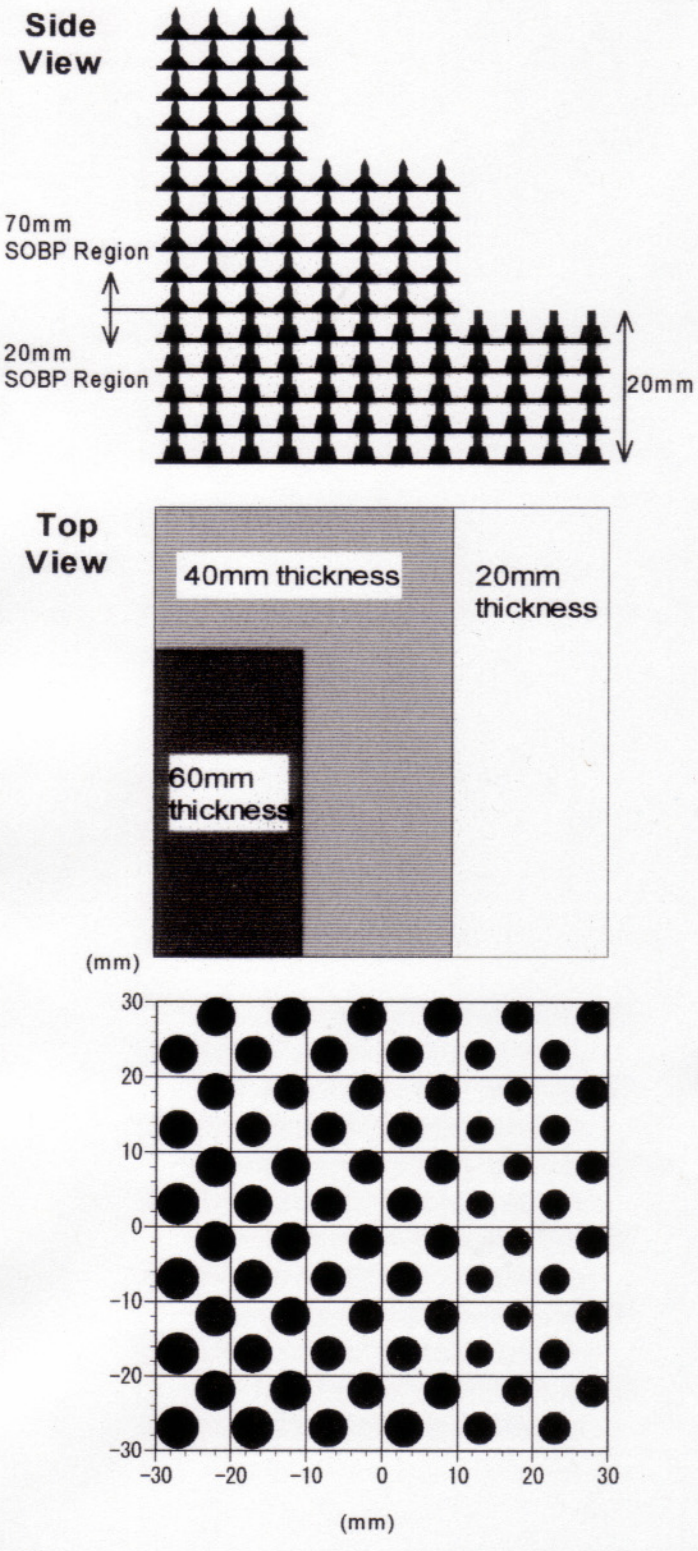
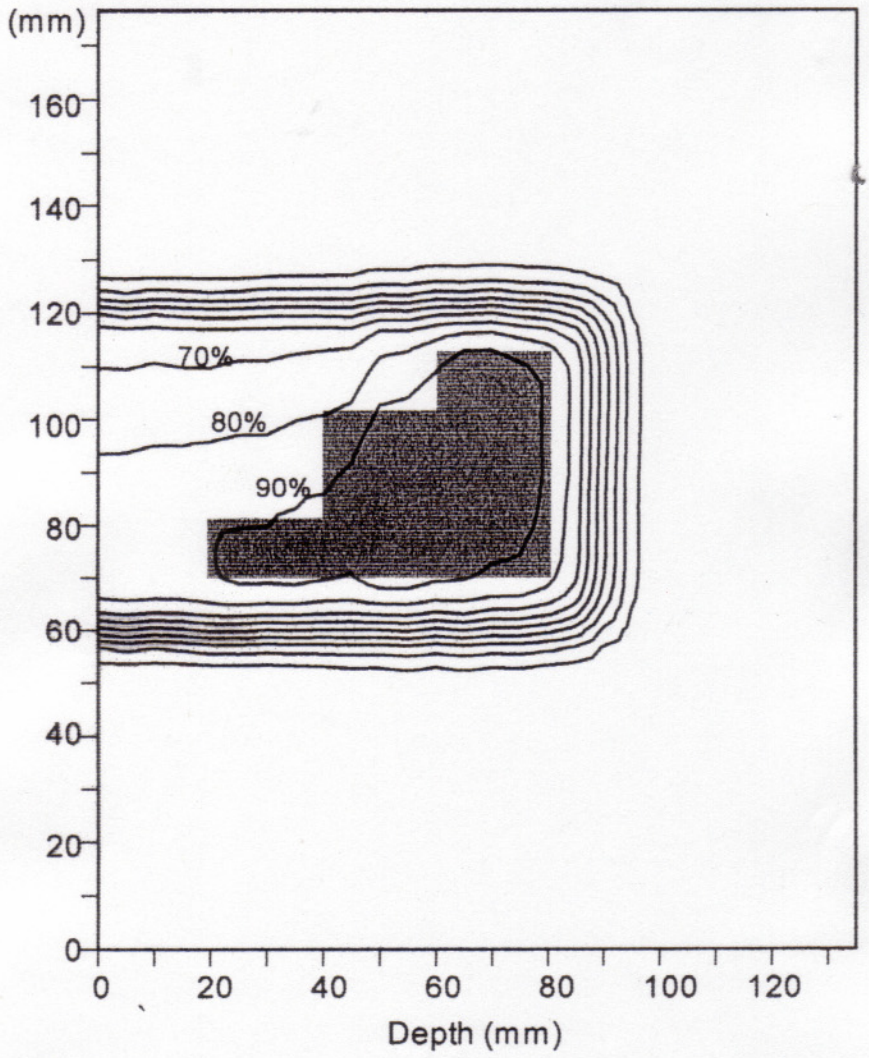


1cm pencil Beam

Schematic View of the Intensity Distribution on the Scanning Spots

Experimental result of the conformal proton irradiation using the new filter and beam scanning.

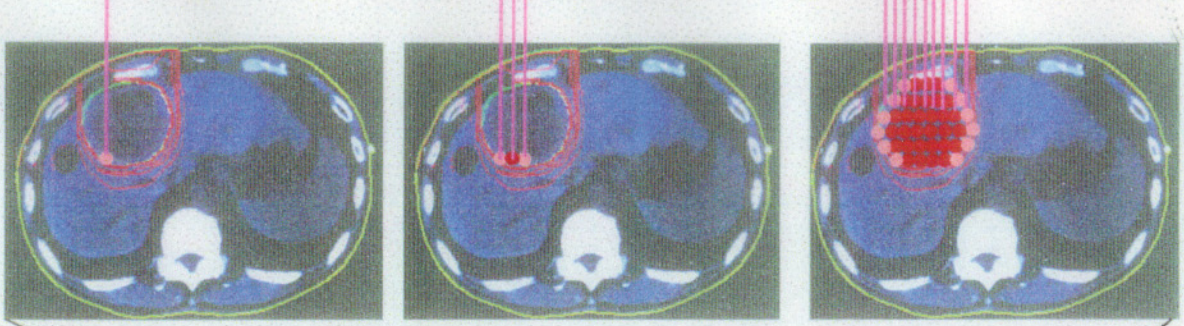


The dotted area is the target trimmed to consider the lateral penumbra by 1cm pencil beam.

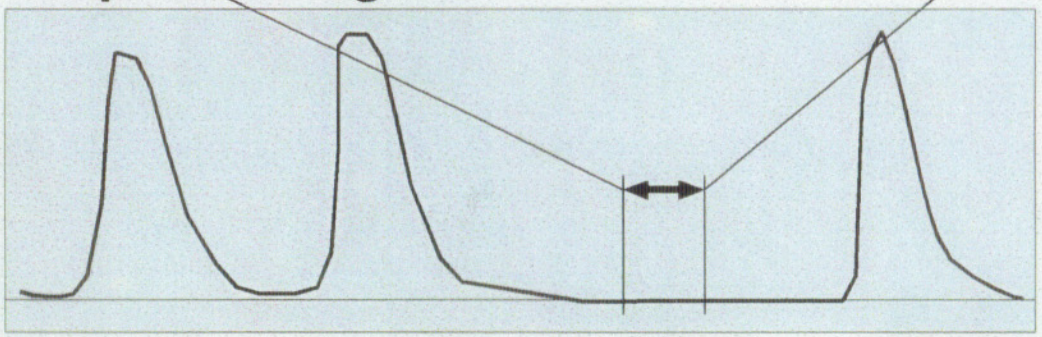
In this case . We need fast scanning for Moving target .

This means we can use small gantry without scatterer .

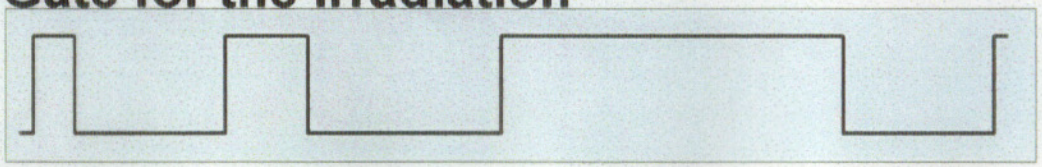
Fast beam scanning for gated irradiation or irradiation in halted respiration



Respiration signal



Gate for the irradiation



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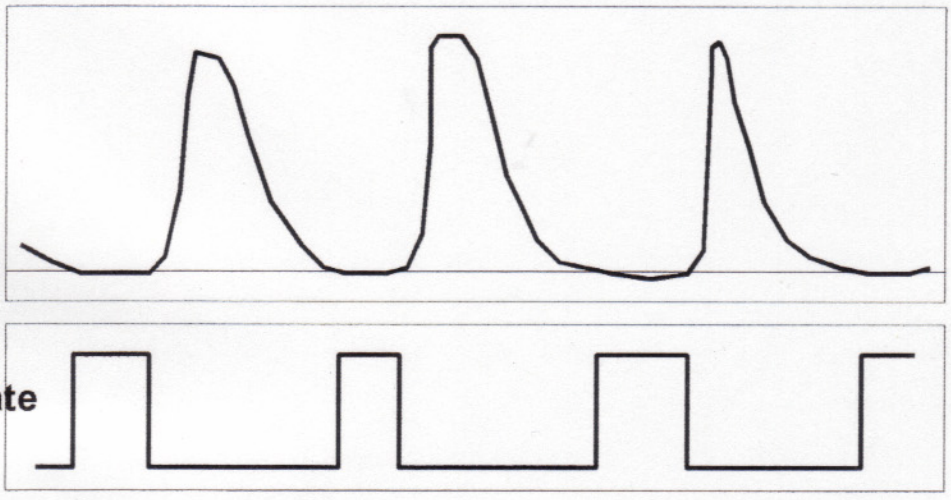
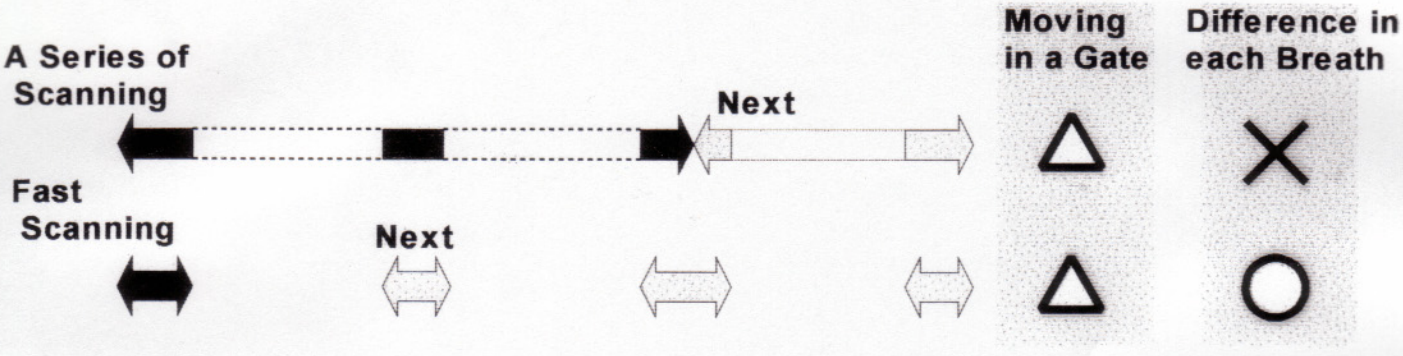
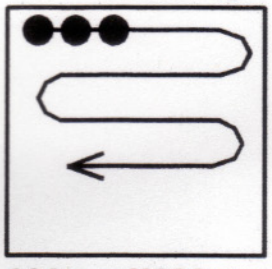
Beam Scanning for Respiration Gated Irradiation





2-D Scanning



200mmX200mm

20X20 = 400 spots 10mm scanning/spot

0.4 sec 1msec/spot

1k ~~500~~ Hz

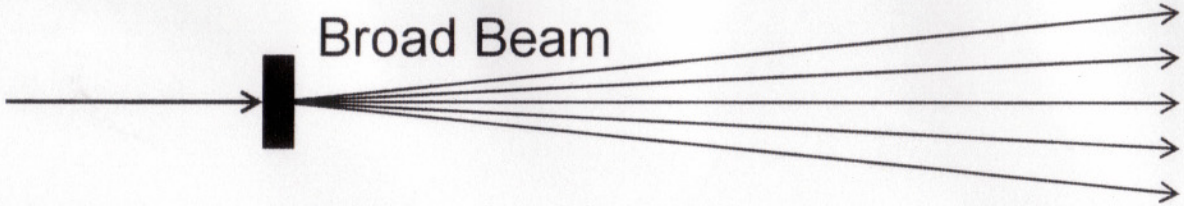
Breath 20 , Dose 4Gy → 10^8 protons/pulse

Intensity Controllability of FFAG

(1) Ion Source	Slow
(2) Scraper	Slow
(3) Timing structure of Injection	Fast ?
(4) Extraction pulse structure	?

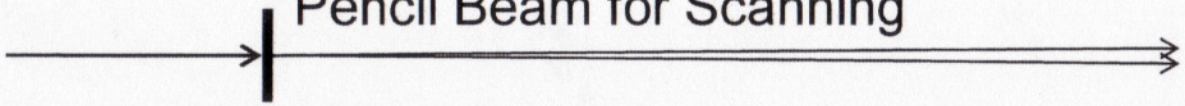
No Feedback Path for High Intensity Operation

Typical Dose Rate for Proton Therapy



Old PMRC (KEK Booster S)
20Hz, 50nsec Pulse
4×10^9proton/p=3mGy/p
Dose Control:
Accumulating Pulses

New PMRC
Slow Ext., 0.3Hz, 0.1s Pulse
10^{11}proton/p=0.1Gy/p
Dose Control:
Stop during a pulse

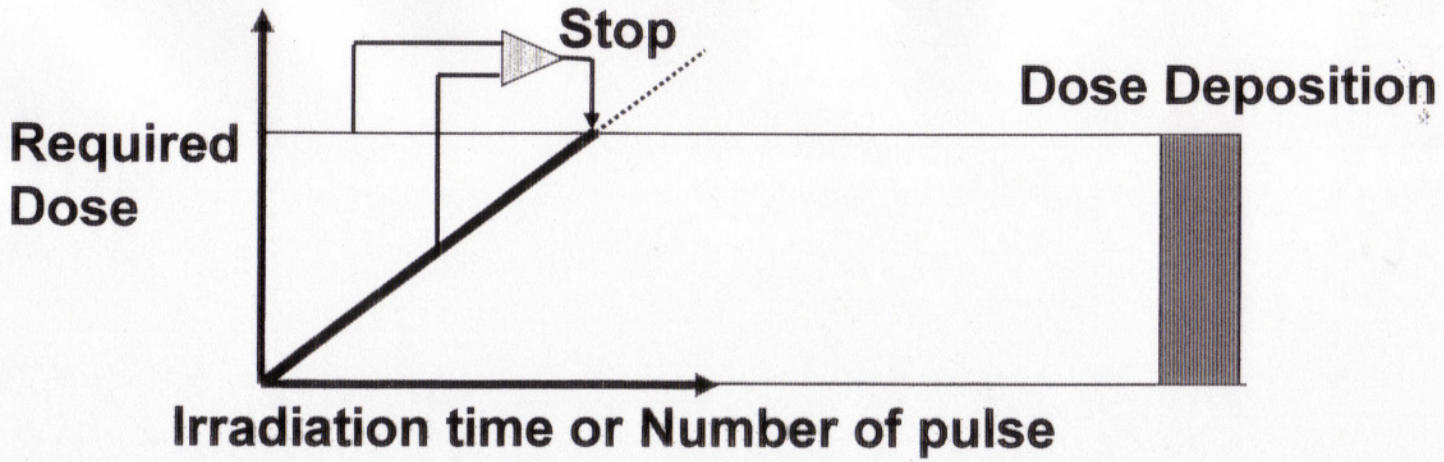


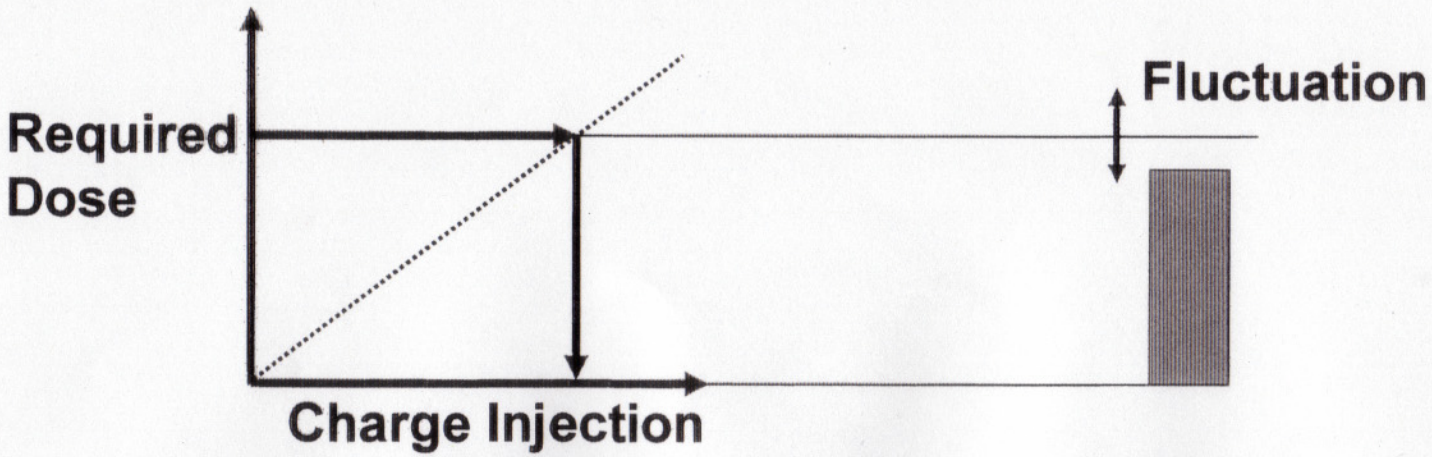
10^9proton/p=1Gy/p
Dose Control: ?

If one can not stop the irradiation during the pulse, the intensity must be too much for proton therapy.

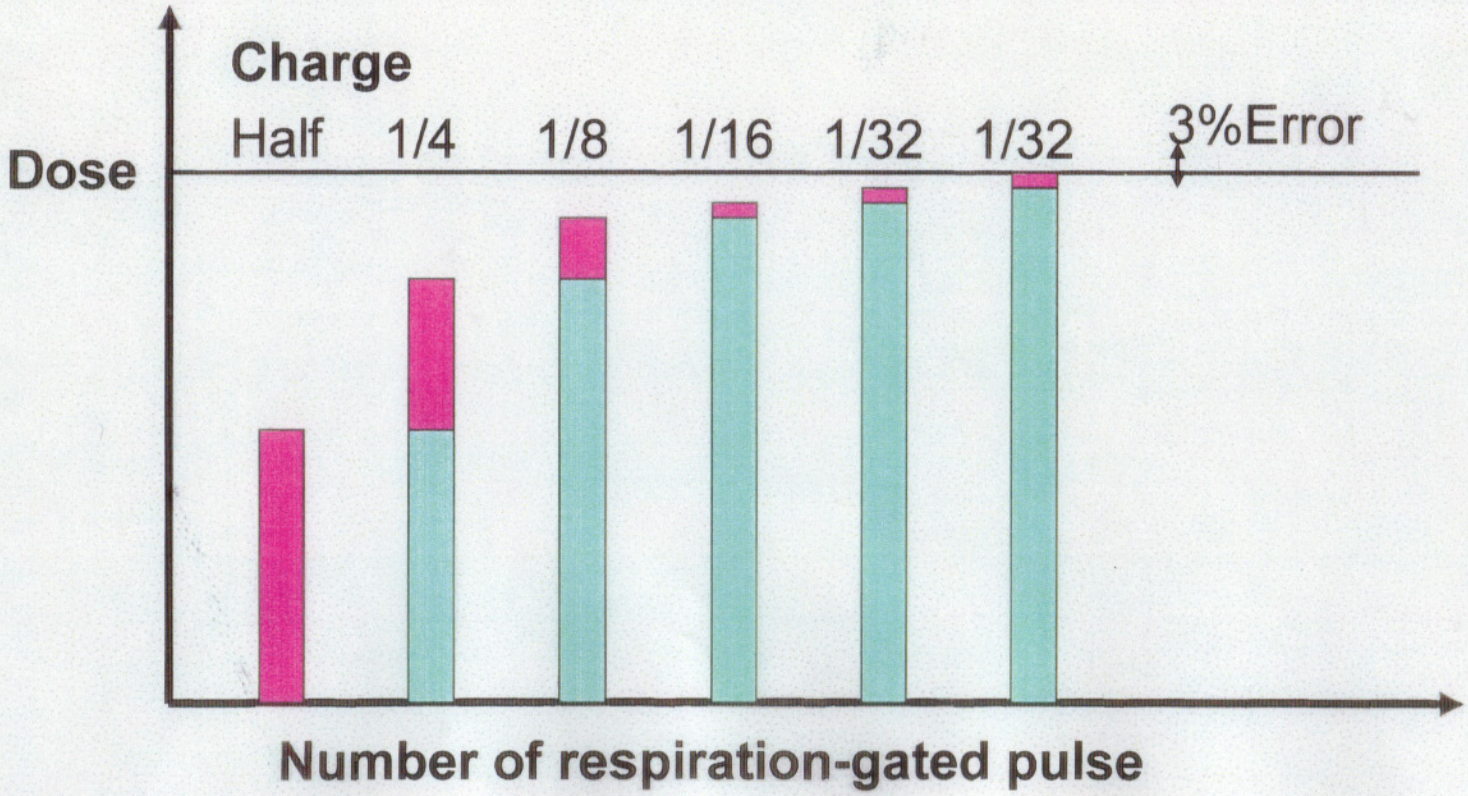
For Conformal Irradiation
Possibility 1 : Low Intensity Operation (mGy/p)
Controllable
Possibility 2 : High Intensity Operation (Gy/p)
How to control the dose ?

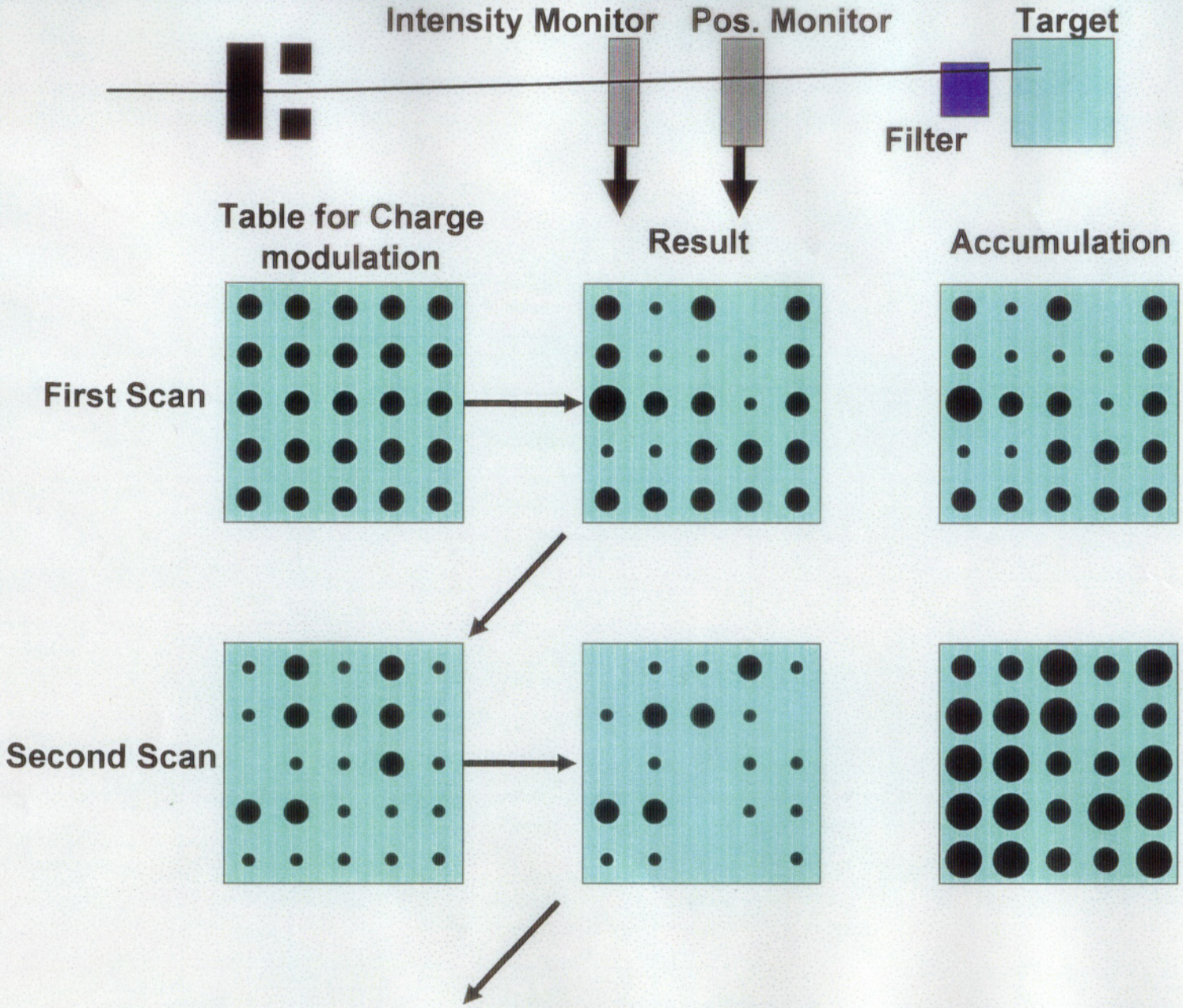
Feedback and non-Feedback Control for Dose Deposition





Successive dose accumulation by charge modulation




Intensity Monitor
Pos. Monitor
Target
Filter
Table for Charge modulation
Result
Accumulation
First Scan
Second Scan