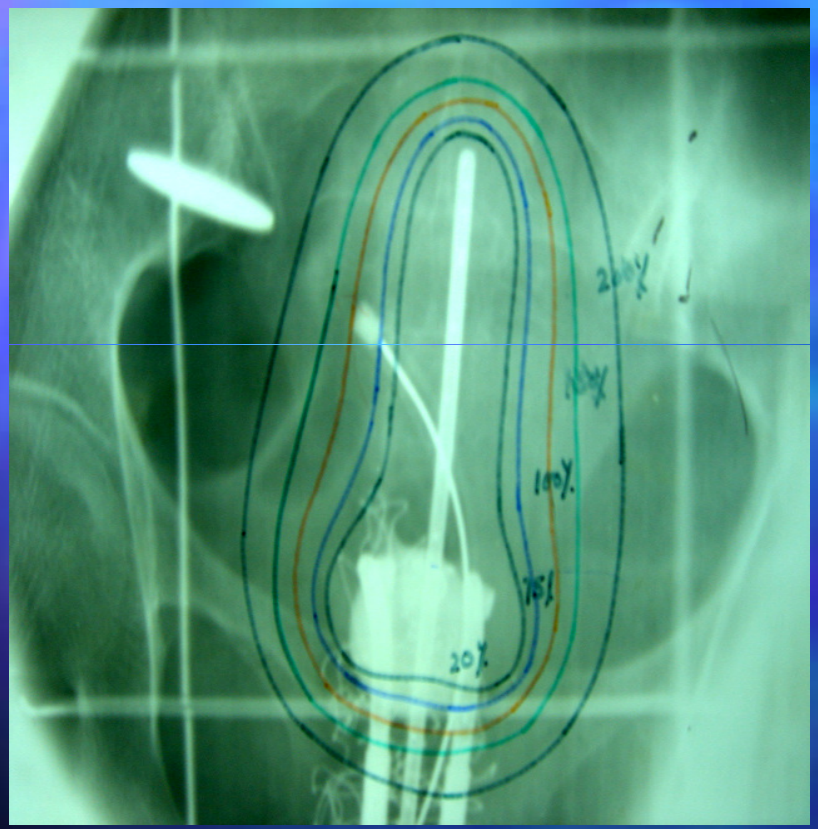
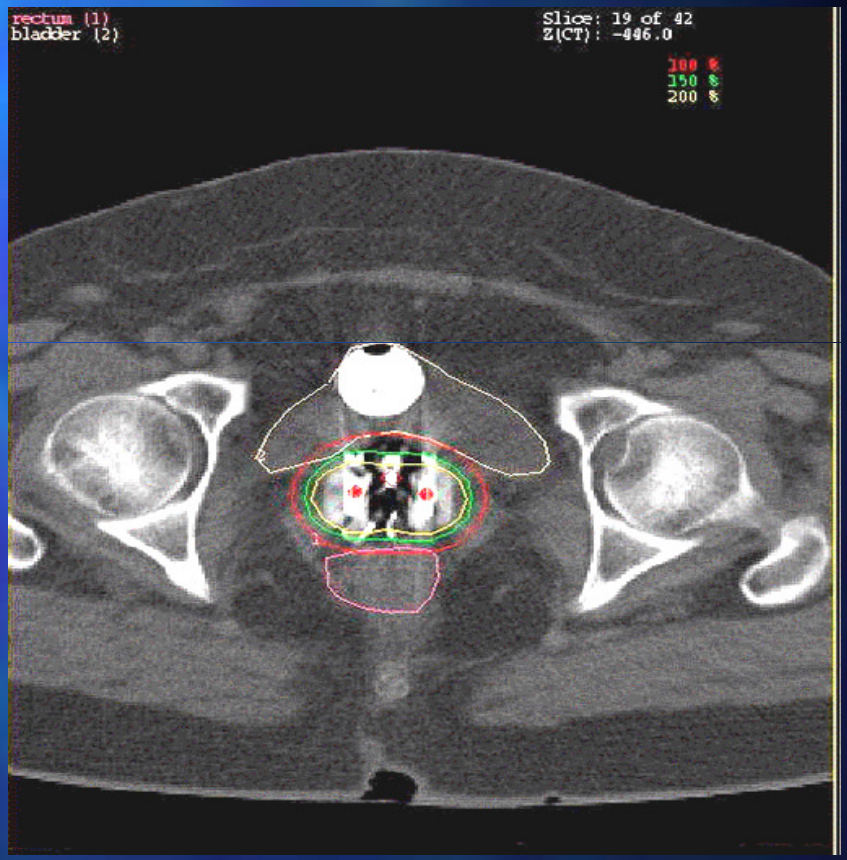
BRACHYTHERAPY SOURCES, BASIC PHYSICS: LDR,MDR,HDR





History - Brachytherapy

1896 – Becquerel - Radioactivity
1898 – Madam Curie / Pierre Curie - Radium
1903 – Nobel Prize for Curie's & Becquerel
1903 – First successful case of malignancy basal cell carcinoma of face
1920 – Patterson & Parker tables for Radium
1920 – Paris system of IC Rx / Stockholm System
1934 – Manchester System
1953 – Tod & Meridith point A & B defined
1957 – Ir – 192 in implants
1965 – Paris system – Interstitial

HISTORY-BRACHYTHERAPY

1960 – Preloaded applicators Stockholm, Paris & Manchester

1960 – After-loading applicator - Henchke / Fletcher-suit

1962 – First Remote after-loading machine

1970 – CO 60 HDR

1985 – HDR Ir- 192

2000 – 3D Brachy planning

- CT/MR Compatible applicators
- Inverse planning

TMH - Brachytherapy

1941 – Established
1962 – DAE
1941 – Radon seeds Radon Plant
1960 – Preloaded (Manchester System) CO-60 / CS – 137 tubes
1962 – gold seeds
1972 – Manual After-loading (Howard)
1976 – CS -137 needle for implants
1981 – Remote after-loading (Selectron)
1981 – Ir - 192 wire implants
1986 – Ir - 192 after-loading microSelectron LDR
1994 – Ir- 192 microSelectron HDR
2005 – 3D Brachy Planning

COMMON RADIOISOTOPES FOR BRACHYTHERAPY

ISOTOPE	ENERGY Mev	FORM	HALF LIFE	APPLICATION
Radium 88Ra226	ν 0.8	Tubes, Needles	1600 Y	IC, Interst. (Historic)
Caesium 55Cs137	ν 0.66	Tubes, Needles, Seeds	30 Y	IC, Interst.
Cobalt 27Co60	ν 1.13, 1.25	Tubes, Needles, Seeds	5.26 Y	IC, Interst.
Iridium 77Ir192	ν 0.35	Wire Pellete	74 d	IC, Interst.
Iodine 53I125	ν 0.028	Seeds	60 d	Interst. permenant
Strontium 38Sr90-39Y90	β 0.2	-	3.8 d	Opthalmic, Pit, Coronary
Gold 79Au198	ν 0.42	Seeds	2.7 d	Interst. permenant

NEW ISOTOPES

ISOTOPE	ENERGY Mev	FORM	HALF LIFE	APPLICATION
Tantalum 73Ta182	v 1.45	Wire	115 d	Interst.
Palladium 46Pd103	v 0.021	Seeds	17 d	Interst. permenant
Sumarium 62 Sm 145	V 0.414	Seeds	40 d	Intert.
Americium 95Am241	V 0.595	Seeds	432 d	Interst. , permenant
Ytterbium 70 Yb 159	V0.928	Seeds	32 d	Interst., permenant

BRACHYTHERAPY DOSIMETRY

Early treatments of Radium - No physical or biological basis, empirical

INTRACAVITORY BRACHYTHERAPY:

1911: Stockholm System - Forsell
2 -3 applications at 3 weekly intervals, each lasting 27-30 hrs.

1920: Paris System - Regaud
1 application over 6-8 days

1934: Manchester System - Paterson & Parker
8000 R to point A, over 140 hrs. divided into 2 equal applications

ICRU 38

BRACHYTHERAPY DOSIMETRY

INTERSTITIAL BRACHYTHERAPY

Manchester System (Paterson - Parker) :

milligram hours of Radium needed to deliver 1000R
planar & volume implants
surface moulds
differential activity

Paris System (Pierquin- Deuterix):

Iridium 192 as isotope
Reference isodose: 85% of basal dose rate
Equidistant, parallel, rectilinear radioactive lines
Equal linear activity

BRACHYTHERAPY DOSIMETRY

INTERSTITIAL BRACHYTHERAPY

Quimby System:

Uniform distribution of sources of equal linear activity
non uniform distribution, higher in the central region of the treatment volume

Memorial System:

Extension of the Quimby System
Complete dose distributions around lattices of point sources of uniform strength spaced 1 cm. Apart
Computer generated dose distributions

BRACHYTHERAPY DOSIMETRY

LDR: 0.4-2 Gy/hr

MDR: 2-12Gy/hr

HDR: >12Gy/hr

Mathematical models for radiobiological equivalence:

- **NSD (nominal standard dose)**
- **TDF (time dose fractionation)**
- **CRE (cumulative radiation effect)**
- **LQ model - most widely accepted**
- **BED/ERD (biological equivalent dose/ extrapolated response dose)**

BRACHYTHERAPY DOSIMETRY

INTERSTITIAL BRACHYTHERAPY

Computer Dosimetry System:

Development of advanced treatment planning computers
Flexibility to deviate from established dosimetry systems
Optimise isodose distributions according to clinical needs
May try to compensate for poor implant geometry

Stepping Source Dosimetry Systems:

Evolution of HDR & PDR systems
High activity, single, miniaturised source
Dwell time is a function of prescribed dose, geometry of the application and source strength on the day of application.

BRACHYTHERAPY DOSIMETRY

Dosimetric steps on treatment planning systems:

- Patient data
- Selection of source data
- Selection of reconstruction methods
- Appropriate orientation of implant geometry
- Dose point descriptions if appropriate
- Dose distribution and evaluation

BRACHYTHERAPY DOSIMETRY

ICRU 38

- Specification of treatment technique
- Reporting of total reference air kerma
- Reference volume be described in terms of height, width and thickness, the volume enclosed by the 60Gy isodose surface.
- Absorbed dose at reference points in organs at risk (bladder, rectum)
- Absorbed dose at reference points related to bony structures
- Specification of time dose pattern

BRACHYTHERAPY DOSIMETRY

ICRU Recommendations for dose specification in brachytherapy

Gross tumor volume: (GTV)

Actual mass of tumor

Clinical target volume: (CTV)

Actual mass of tumor plus occult disease

Planning target volume: (PTV)

Identical to CTV as it does not need the margin for patient motion

Treatment volume: (TV)

Volume of tissue, based on the actual implant, that is encompassed by the peripheral dose isodose surface

BRACHYTHERAPY DOSIMETRY

ICRU Recommendations for dose specification in brachytherapy

High dose regions:

Corresponds to 150% of the mean central dose

Low dose regions:

Corresponds to any region withinnthe target volume that receives 90% or less of the mean central dose

Dose uniformity:

Ratio of the peripheral dose to the mean central dose
It is 75% +/- 7%

BRACHYTHERAPY DOSIMETRY

3-D RECONSTRUCTION METHODS

ORTHOGONAL

SEMI-ORTHOGONAL

ISOCENTRIC

STEREO SHIFT

VARIABLE ANGLE

BRACHYTHERAPY DOSIMETRY

HDR TREATMENT PARAMETERS

MACHINE	PATIENT
Positions	Dose prescription point
Time	Treatment length

BRACHYTHERAPY DOSIMETRY

OPTIMIZATION

Optimization in high dose rate system is the technique in which a uniform dose distribution of the applications with rigid catheters or tubes or needles by adjusting the dwell time of the stepping source in each dwell position

NON OPTIMIZATION

In this the dwell time of the stepping source in each dwell position is the same

BRACHYTHERAPY DOSIMETRY

OPTIMIZATION

GEOMETRIC OPTIMIZATION- DISTANCE, VOLUME

DOSE POINT OPTIMIZATION- DISTANCE, VOLUME

POLINOMIAL OPTIMIZATION- DISTANCE, VOLUME
(WITH OR WITHOUT DTGR)

(DTGR - DWELLTIME GRADIENT RESTRICTION)

BRACHYTHERAPY DOSIMETRY

Geometric Optimization

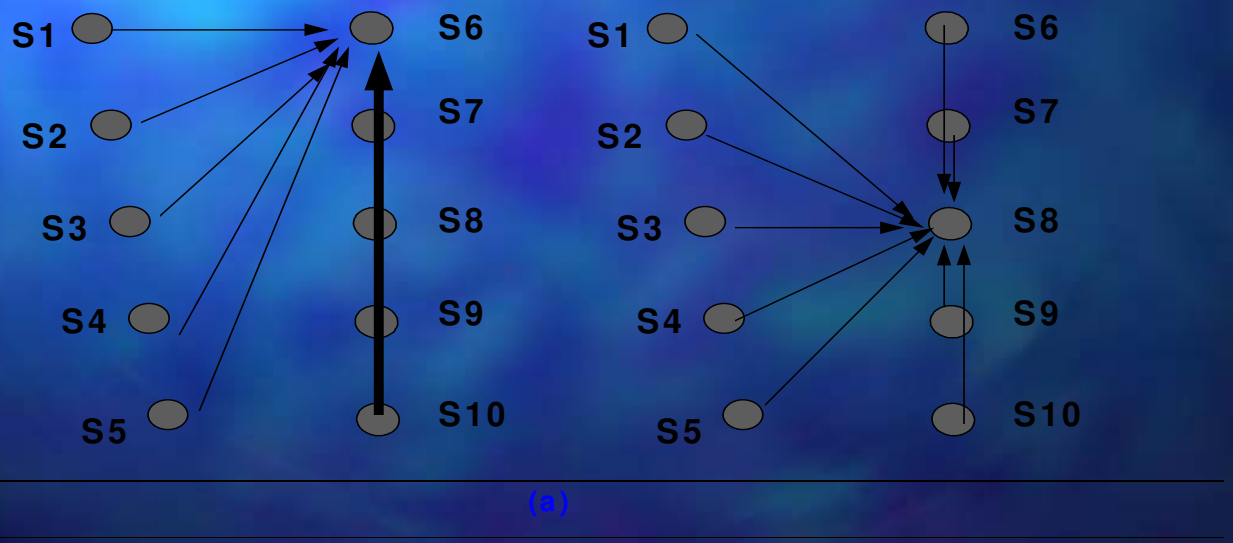
Optimizing on distance:

dwell positions are also used as dose points

Optimization on distance is obtained by taking all dwell positions in to account. Is done on a single plane implant

Optimizing on volume:

Is done on multi plane volume implants aiming at a homogenous dose distribution in the target volume. Optimization in volume uses only the dwell positions in other catheters



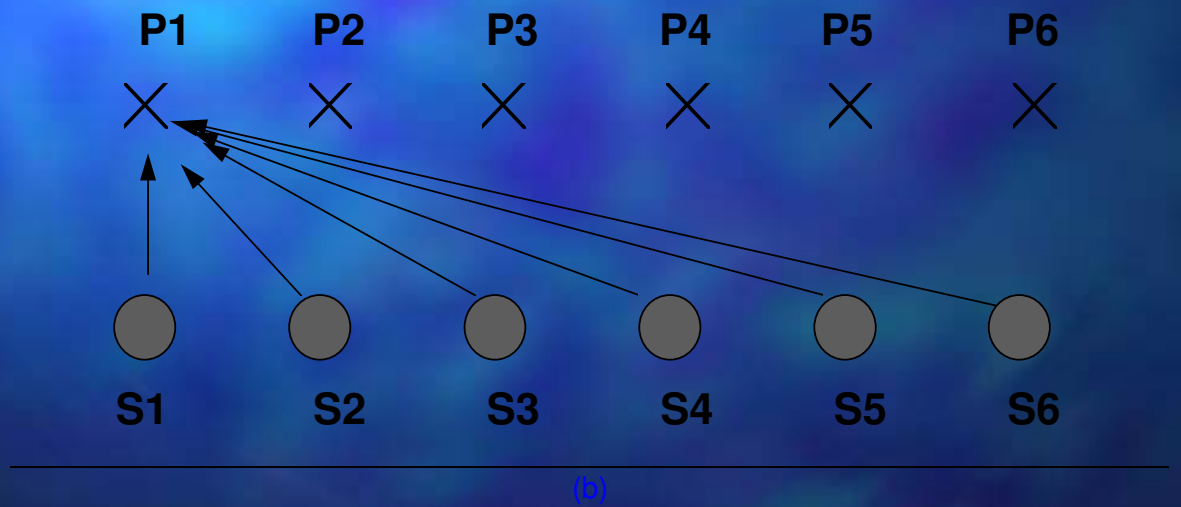
BRACHYTHERAPY DOSIMETRY

Dose point optimization

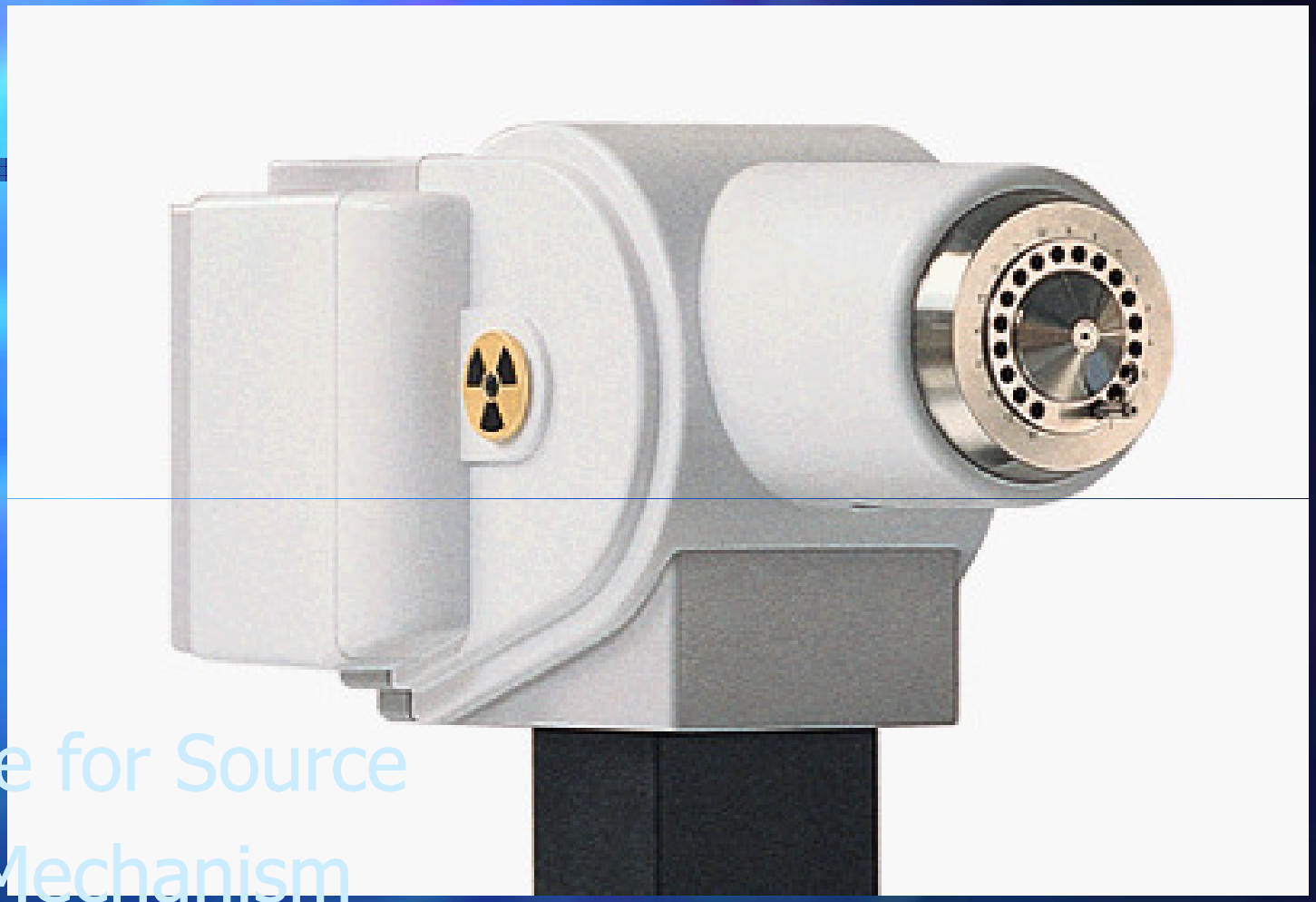
Number of dose points defined along the axis of catheters at a constant distance from each dwell position

Polynomial Optimization

Approximates the dwell times along the catheter as a function of the distance to the first dwell position in that catheter. DTGR taken in to account

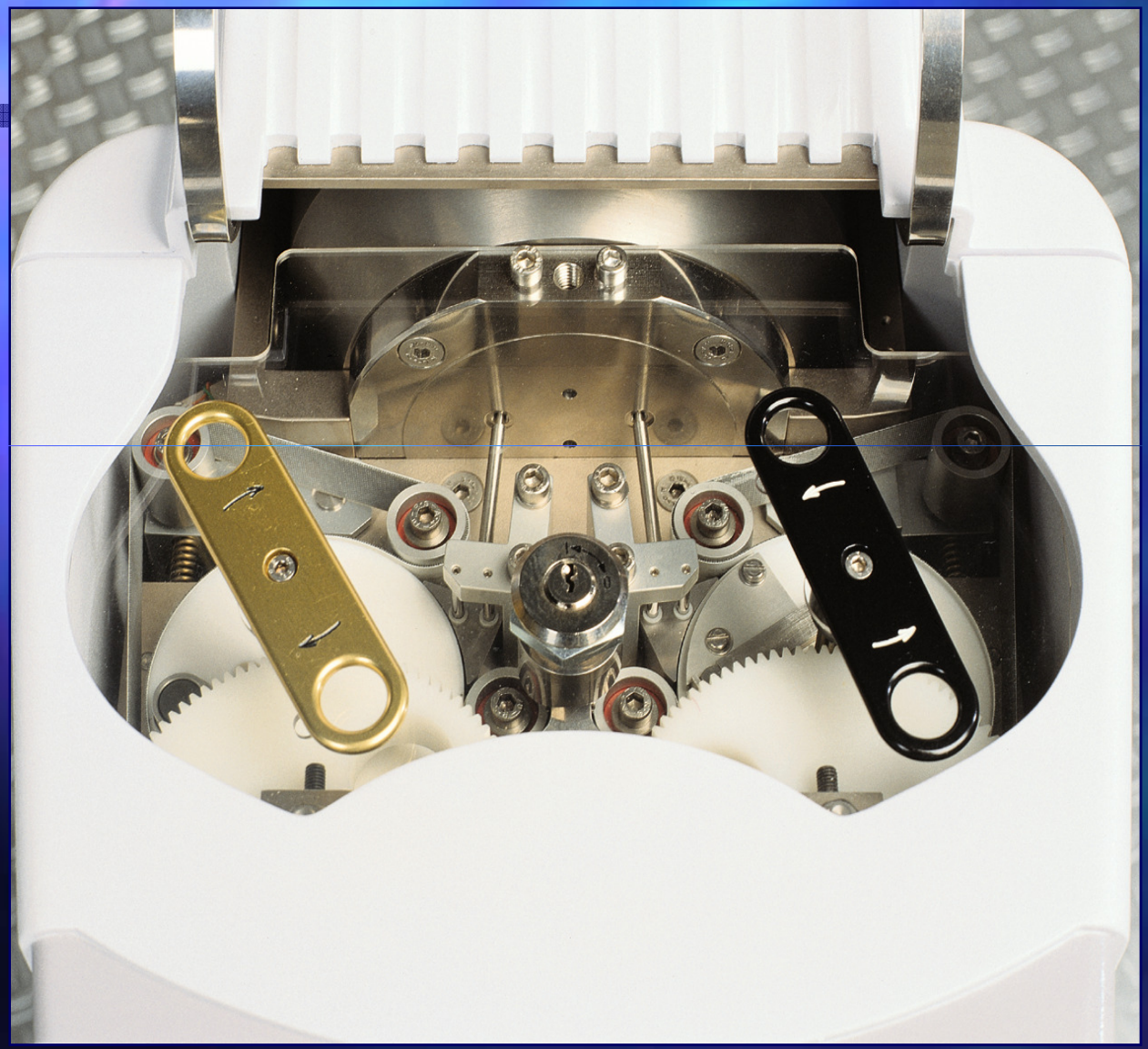


HDR MACHINE



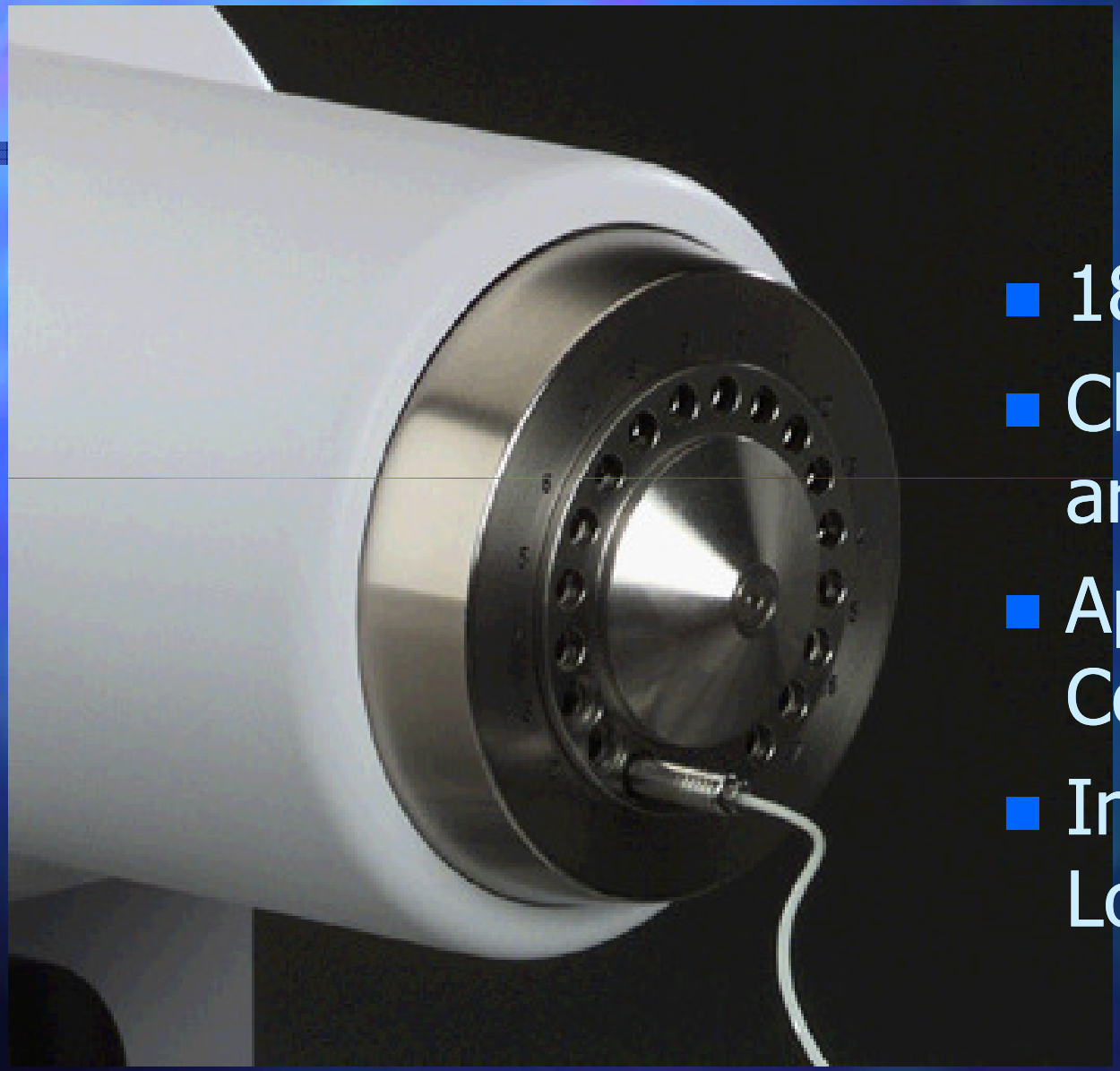
- Storage for Source
- Drive Mechanism
- Indexer
- Emergency System

CHECK & SOURCE CABLE DRIVES



- Safe, < 0.1µSv/h
- Stepper Motors, 50 cm/s
- Check Cable Drive
- Built-in Radiation Detector
- Lift

INDEXER OVERVIEW



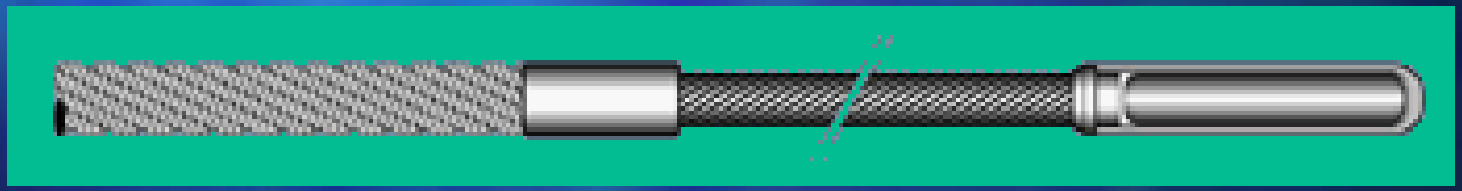
- 18 Channels
- Channel 1-3 are keyed
- Applicator Connected
- Indexer Locked

HDR TREATMENT CONTROL STATION

- Modern graphical user interface
- Extensive database for recording treatment history
- Record & verify integrated

SOURCE SPECIFICATIONS

- Single ^{192}Ir source
- 0.9 mm diameter, 4.5 mm long
- 10 Ci, High Dose Rate
- Sealed source attached to drive cable to move it forward and backward

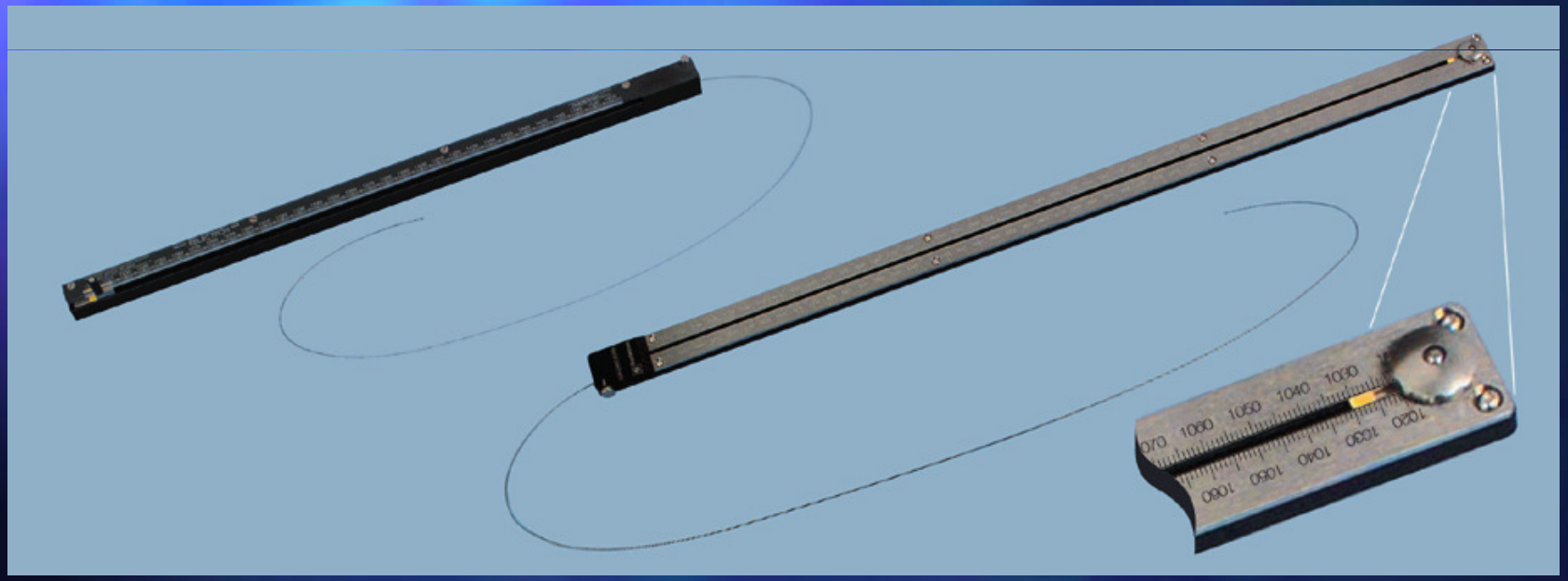


CHECK RULER

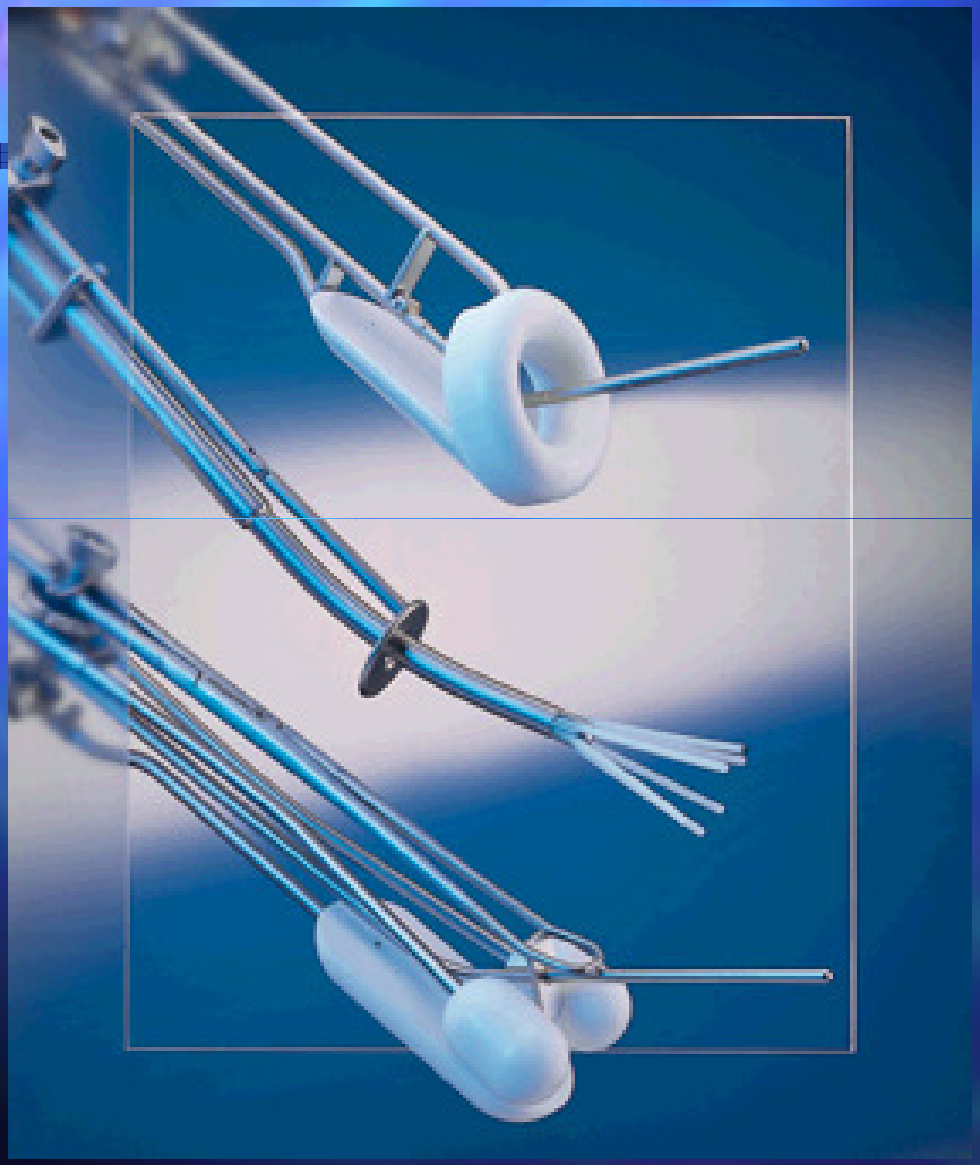
- Verify any source position in any treatment channel
- Daily QA check
- Simple and easy to use

SOURCE POSITION SIMULATOR

- Measure the depth of a catheter
- Solid wire or X-ray marker



SITES FOR HDR TREATMENT



- Cervix
- Endometrium
- Vagina
- Prostate
- Breast
- Bronchus
- Esophageal
- Bile Duct
- Nasopharynx
- Skin

- Able to store a complete applicator
- Service channel for temporary storage of the source
- Holder for forceps
- Easy to maneuver

HDR QUALITY ASSURANCE

- QA OF HDR UNIT
- CALIBRATION OF SOURCE
- QA OF TREATMENT PLANNING SYSTEM
- QA OF PATIENTS PROCEDURE

HDR MACHINE QA CHECKS

- DOOR INTERLOCKS
- EMERGENCY STOP
- POWER FAILURE
- OPENING OF INDEXER COUPLING
- TIMER CHECK
- APPLICATORS & TRANSFER TUBES INTEGRITY

HDR MACHINE QA CHECKS ---

- CHECK CABLE RUN
- EXTRA CHECK CABLE RUN
- SOURCE POSITION ACCURACY
- SOURCE ACTIVITY CHECK

HDR SOURCE CALIBRATION

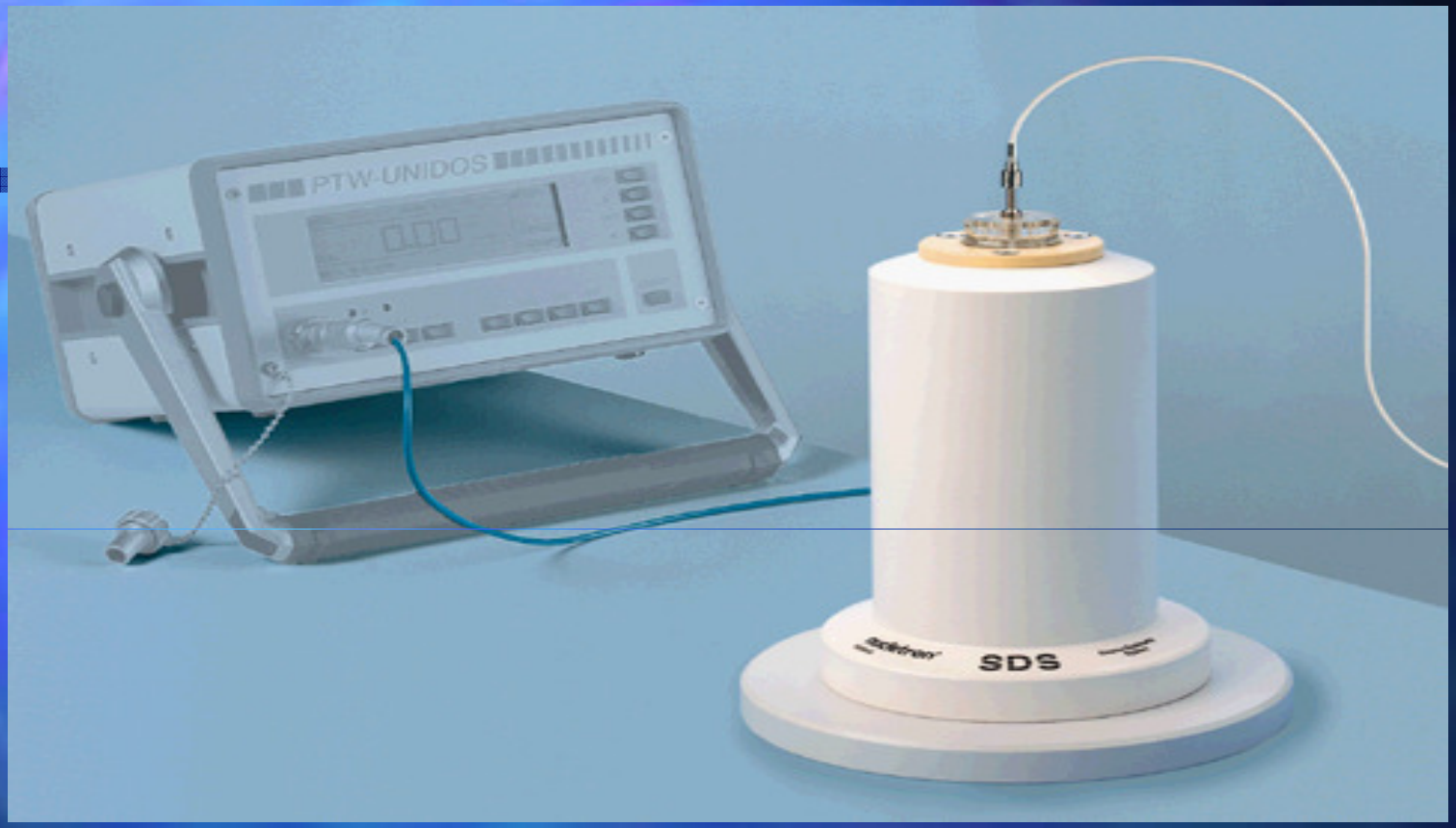
- AIR KERMA MEASUREMENT
- WELL TYPE CHAMBER
- SECONDARY STANDARD DOSIMETER
- SPECIAL JIG
- CERTIFICATE VALUE
- PERIODIC VERIFICATION

QA OF TPS

- INPUT PARAMETERS:SOURCE COORDINATES, DOSE POINTS, etc.
- RECONSTRUCTION ACCURACY
- MANUAL VERIFICATION
- TEST CASES
- PERIODIC ACTIVITY CHECKS

HDR QA CHECK LIST
BEFORE THE TREATMENT

- Proper selection of the patient imported from PLATO
- system checks
- date & time of the system
- Activity & decay correction
- safety interlocks, warning lights, CCTV Camera,
- Zone monitor etc
- Printer paper available
- Emergency procedures available
- Emergency container available
- Source unlock
- Patient couch locked, Indexer locked etc



- Source Dosimetry System
- Electrometer
  - Direct Readout of the source strength

Calibration Factors supplied by the Manufacturers

Calibration Factor	Units
•Air Kerma Strength	$Gy.m^2.h^{-1}.A\text{-}1$
•Exposure Strength	$R.m^2.h^{-1}.A^{-1}$
•Activity	$GBq.nA^{-1}$ or Ci/A^{-1}

In our HDR Chamber-Nucletron SDS-the typical calibration factor given is 2.301×10^{8} Ci/A

METHOD-1:WELL TYPE IONISATION CHAMBER]

The source strength(S_i) is calculated from the following formula:

$$S_i = M \times N_x \times P_{ion} \times K_{t,p}$$

where

M is the measured reading in nA,

N_x is the calibration factor in Ci/nA,

P_{ion} is the reciprocal of ion collection efficiency factor,

$K_{t,p}$ is the temperature and pressure correction factor.

The measurements of the activity for ten Ir-192 sources with the Source Dosimetry System (SDS) as compared to the manufacturer's certificate values.

Source No.	Date	SDS Reading	Certificate	% Var.
		Ci	Ci	
1	16.06.1994	10.13	10.00	+ 1.2
2	11.10.1994	9.14	9.28	- 1.5
3	29.01.1995	11.10	10.70	+ 2.6
4	14.06.1995	10.54	10.59	- 0.5
5	20.10.1995	8.57	8 . 42	+ 1.8
6	22.03.1996	8.25	8 . 21	+ 0.5
7	26.06.1996	9.59	9. 84	- 2.5
8	29.10.1996	10.80	10.55	- 2.4
9	26.02.1997	10.95	10.87	+ 0.73
10	04.08.1997	10.36	10.28	+ 0.70

METHOD:2 [SECONDARY STANDARD DOSIMETER]

The air-kerma rate (K_{air}) at 1 meter is calculated by the following formulation:

$$K_{air} = M \times N_x \times K_{t,p} \times (d/100)^2 \times K_{att} \times f$$

N_x is the exposure calibration factor in R/reading traceable to national standardization laboratory,

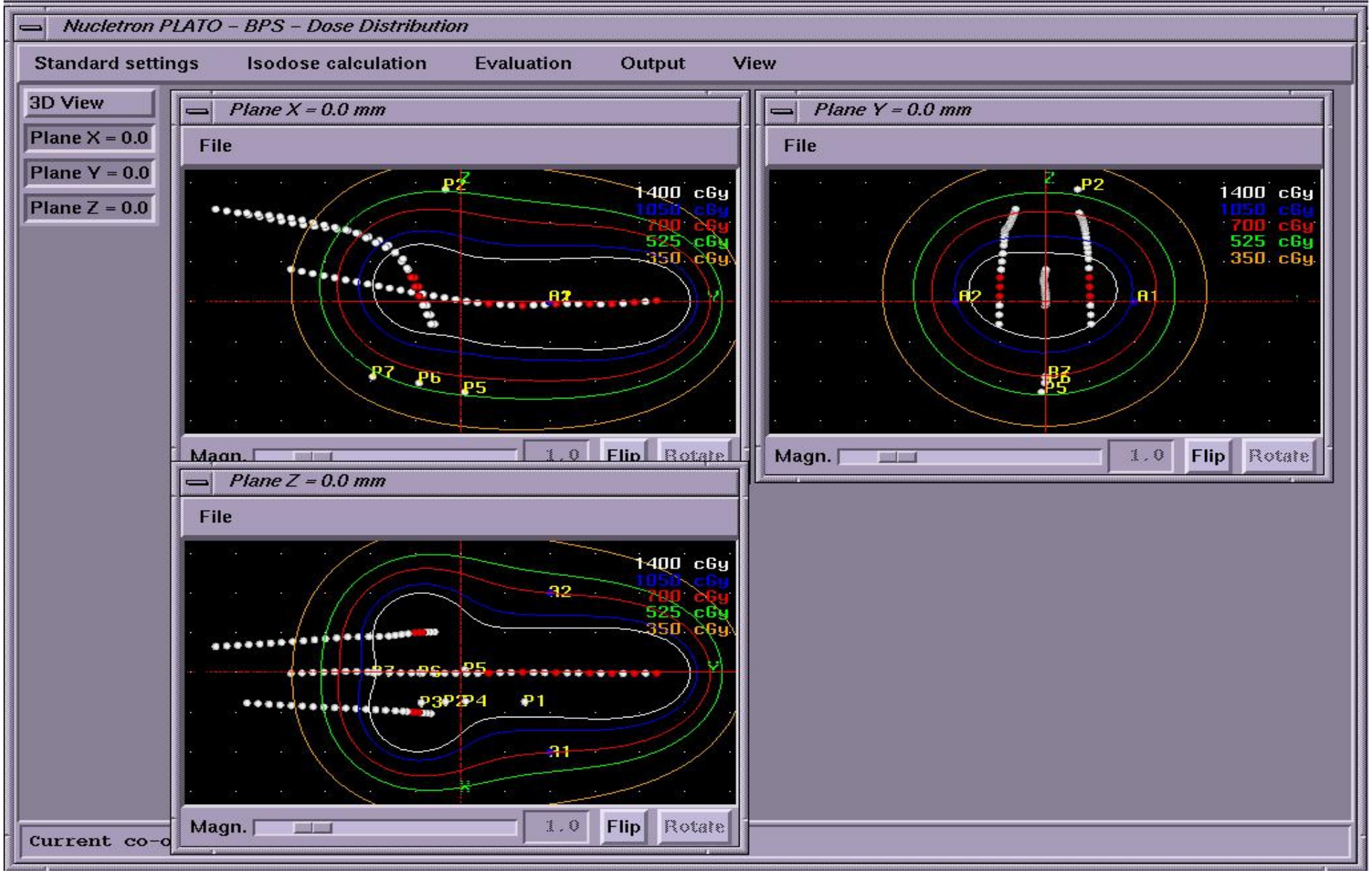
$K_{t,p}$ is the temperature and pressure correction factor,

d is the distance between the source and the chamber center in cms.,

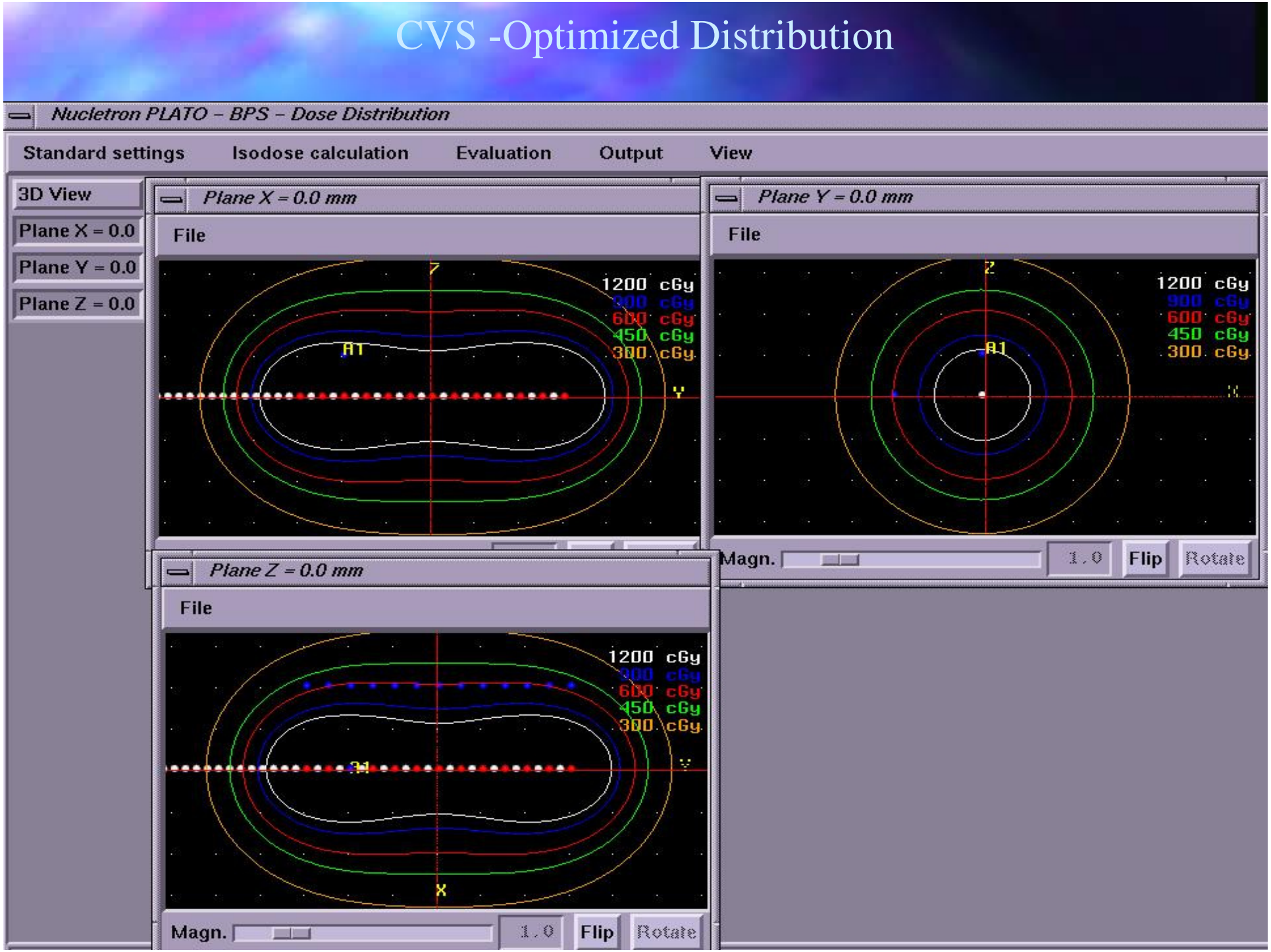
K_{att} is the wall attenuation correction factor for the attenuation beyond electron equilibrium thickness,

f is the Roentgen to Rad conversion factor.

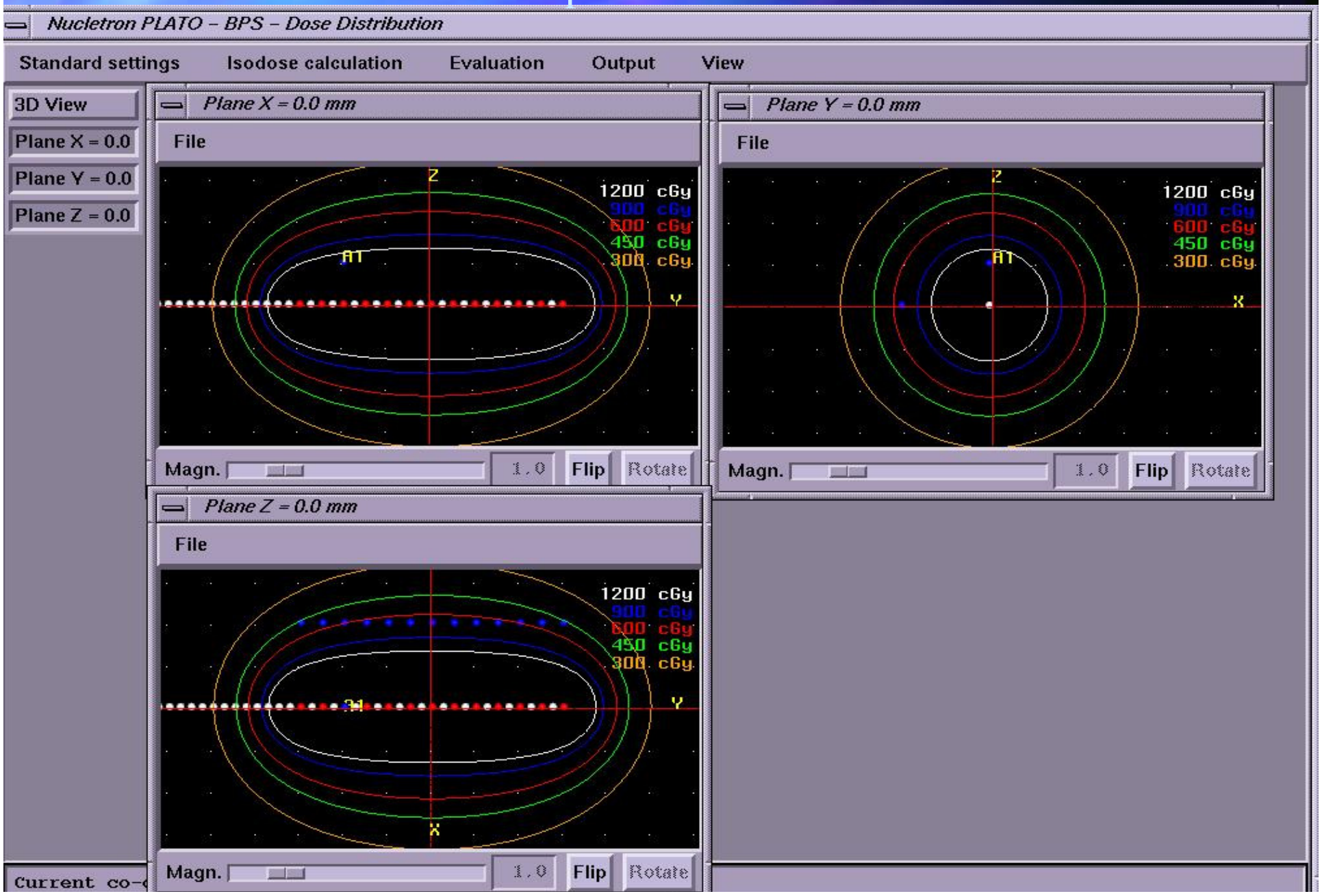
Intracavitory Application



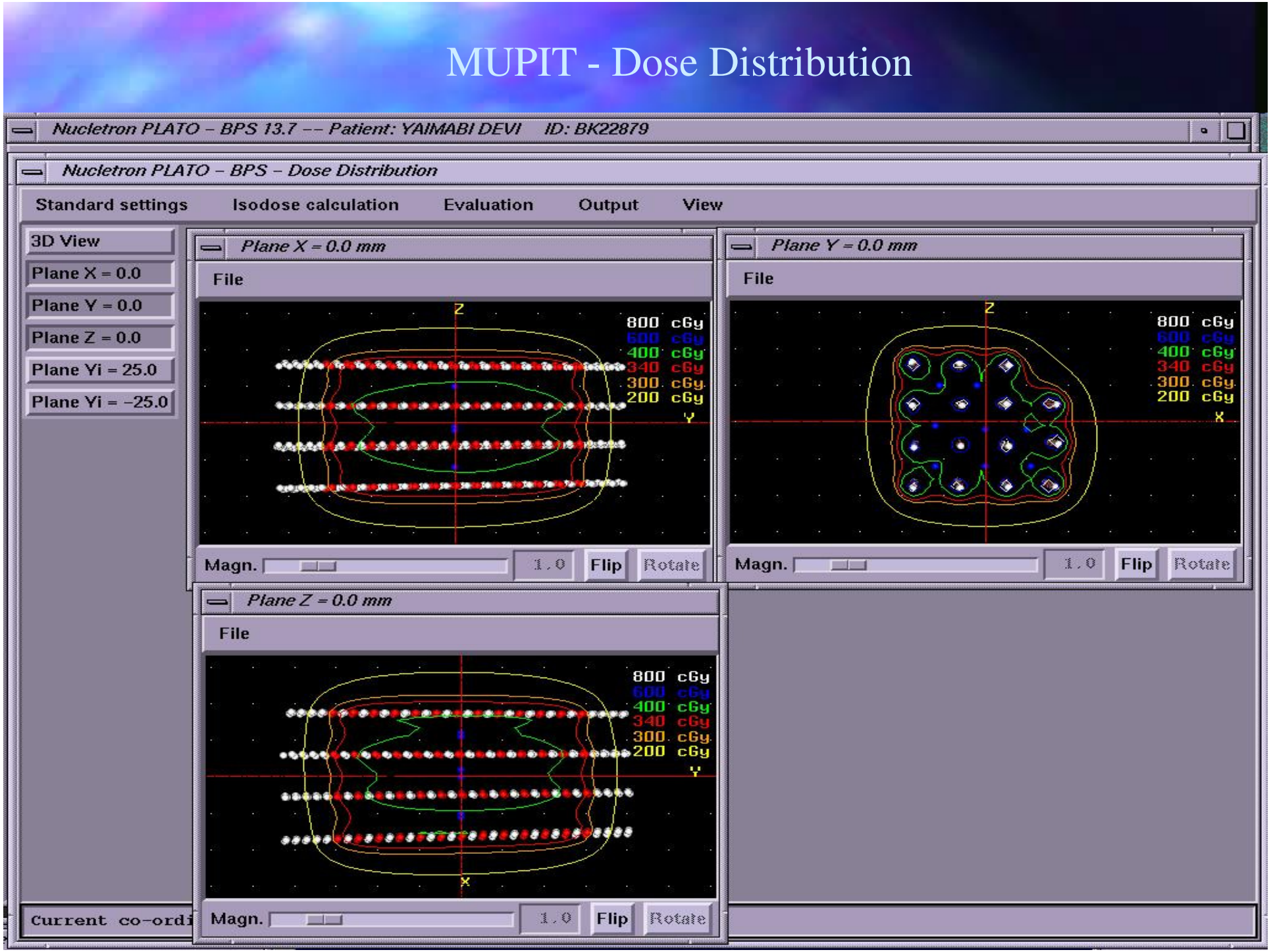
CVS -Optimized Distribution



CVS- Non optimized Distribution



MUPIT - Dose Distribution



DOSE RATE – LDR-HDR

Increasing the dose rate produced increased biological effects which are different for tumour & acute responding normal tissues than for late responding normal tissues.

It is, therefore, important to know the number of fractions & total dose that should be chosen so that that HDR brachytherapy produces the same effects is the LDR modality on tumour & normal tissues.

The Linear Quadratic (LQ) model is more successful in predicting the early and late reactions as it is derived from micro dosimeteric analysis for cell survival (Dale 1985, Orton 1991)

RADIOBIOLOGICAL – LQ MODEL

BASIC FORMULA

$$E = n(\alpha d + \beta d^2)$$

Where, E = given biological effect

n = number of fractions

d = dose per fraction

α & β = tissue specific linear and quadratic coefficients

By dividing both sides by α we get BED, Biological Effective Dose or Extrapolated Response Dose ERD

$$BED = E / \alpha = D \{ 1 + d / (\alpha / \beta) \}$$

The factor $1 + d / (\alpha / \beta)$ is called Relative Effectiveness, RE

It is a factor by which isoeffect dose is less than the continuous low dose rate, when dose per fraction d is used.

α / β is very useful quantity. From large no. of clinical data values for this ratio is taken as 3 Gy for late reactions and 10 Gy for early reactions and tumors

This was further modified by Fowler and others (1990),

$$ERD = N\,d\,\{1 + G\,d/(\alpha / \beta)\} - KT$$

Where G= parameter representing rate of repair of sub-lethal damage

K = constant related to cell proliferation

T = overall time

The traditional continuous low dose rates of 50 to 60 cGy/hr have similar values of RE to those of conventional 2 Gy 1 fraction by external beam.

Thus, it was possible to add up the doses of external beams and intracavitary at these dose rates without much error.

However, it is not the case with HDR. Large amount of repair is taking place in both type of schedules (LDR/HDR).

If HDR fraction size (dose) is increased this repair gets lost. The loss is larger for the late than the early or tumour effect.

EQUIVALENT DOSES FOR HDR

Example: (Simplified)

For a standard LDR 60 Gy / 120 h treatment, (for tumor)

$$BED = 60 (1+ 0.5 / 3)$$
$$= 70$$

For HDR, this can be achieved with 5 fractions of 6 Gy
(or any other combinations, TABLE I)

$$BED = N \times d \{ 1 + G\, d/ \alpha / \beta \} - KT$$

$$70 = 5 \times 6 (1 + 0.7 \cdot 6/3) ,$$ **where G=0.7, and proliferation ignored**

TABLE I - HDR DOSES EQUIVALENT OF LDR 50 cGy / H (6000 cGy / 120 H)

NO. of HDR Fractions	Equivalent early normal tissue and tumor effect α / β = 10 Gy	Equivalent late normal tissue reactions α / β = 2 Gy	Equivalent late normal tissue reactions α / β = 3 Gy	Equivalent late normal tissue reactions α / β =4 Gy
30	30 x 202	x 204	x 204	x 203
10	10 x 489	x 407	x 425	x 438
8	8 x 577	x 465	x 488	x 507
6	6 x 709	x 550	x 581	x 608
5	5 x 806	x 611	x 648	x 680
4	4 x 938	x 693	x 740	x 779
3	3 x 1136	x 814	x 874	x 925

Actual fractions to be chosen by carefully weighing the early tumor effect and late normal tissue reaction
(FOWLER 1990)


Thank You.