Calibration for Brachytherapy Sources

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Importance of Brachy Source Calibration for Clinics

- AAPM, ABS and FDA recognize need for accurate calibration in terms of well defined physical quantity.
- The Medical Physicist is responsible for the dose calculated for the patient. Output should be independently validated. - TG-56 & TG-40

AAPM TG-40 Recommendations

- Clinical calibration of at least 10% of seeds prior to implant, for every implant
- Clinical calibration agreement with manufacturer to within 3% of batch mean and maximum 5% deviation from mean
- Institution is responsible for verification of manufacturer calibration using ADCL calibrated instrumentation

ADCL Calibration

- There are only 3 AAPM accredited ADCLs
- TG 40 & TG 56 require a directly traceable calibration
- An ADCL provides directly traceable calibration but no other laboratory

Important Point for Physicists

- Measure your seeds before use.
- There have been examples of dead seeds, some seeds with twice the output of the others in the batch.
- Don't just trust what manufacturer has sent you. Measure it!!!!

Manufacturer LDR Seed Batch Criteria

- Range criteria: 7% (2σ) (± 3.5% -- 1σ)
- Uncertainty of measurement: ±4% (2σ)
- Therefore total range with uncertainty could result in 2 seeds being separated as far as 11%, although most will be within 7% of average. (95 out of 100 within 7%; 5 out of 100 outside of 7%).

Brachytherapy Sources Division

- **Low energy photon sources - LDR applications**
- **High energy photon sources (used for High Dose rate brachytherapy)**
- **Beta brachytherapy sources (used for Intravascular Brachytherapy for prevention of restenosis and Ophthalmic Applicators used to treat eye)**

Output Quantities Traceable to NIST

- Photon Source: Air kerma strength - symbol S_k. Given as unit “U” where U[=]μGy- m^2/h. Values of S_k can be up to 260 U.
- Beta sources: Absorbed dose rate in water done with an extrapolation chamber
  - At a depth (usually 2 mm)
  - At the surface - ophthalmic applicators

Standards at an ADCL

- NIST has transferred calibrations to ADCLs for LDR sources, Intravascular sources and ophthalmic applicators.
  - The UW ADCL maintains these standards at highly precise values.
- HDR ^{192}Ir - a standard does not exist but is used medically, the ADCL is traceable to NIST via a chamber with interpolated calibration factor.

Proficiency Tests

- **Gamma sources: all ADCL Secondary Laboratories fall within ± 0.6%**
- **Beta sources: All ADCL secondary Laboratories fall within ± 2%**
- **Uncertainties for Proficiency tests**
  - **Gamma sources: ± 2% (k=2)**
  - **Beta sources: ± 3% (k=2)**

Uncertainties for ADCL calibrations

- Intravascular photon sources ± 2.5% (k=2)
- Intravascular beta sources

➲ reproducibility of well chambers ± 2% (k=2)

➲ Contribution from primary laboratory is 15% (reduced to 8%) for 2mm absorbed dose to water.

Calibration Quantities and Units

- Apparent activity (milliCurie)
  - Includes reduction of activity based on source output caused by source encapsulation
  - Gamma constant used in conversion from output measurements in air
  - Gamma constant used by manufacturer, clinic and laboratory may differ.
- Not a recommended unit

Calibration Quantities and Units (continued)

- **Air Kerma Strength ($\mu Gym^2/hr$)**
  - ➲ **Actual characterization of source *output* in terms of the *dose* delivered to air. Related to exposure primarily by W/e, which is the average energy required to produce an ion pair in dry air.**
- **Endorsed by the AAPM for use in treatment planning protocols, and adopted in TG 43.**

User Conversion

- The measurement is generally done by Well chambers, which are calibrated in the above quantities.
- Conversion of these quantities to absorbed dose at a given distance is via a protocol, e.g. TG-43. This is done by user.

Present System - LDR

- Air Kerma Strength causes a number of questions amongst medical physicists.
- Need to understand what you are measuring (including seed by manufacturer) and to what it is traceable

Frequently Asked Questions of the UW ADCL (LDR)

- What sources are available
- Which instruments can be used (using Nuclear Medicine counters with wrong source holders)
- Single seed versus batch measurements
- Signal to noise problems
- Chamber and Electrometer constancy

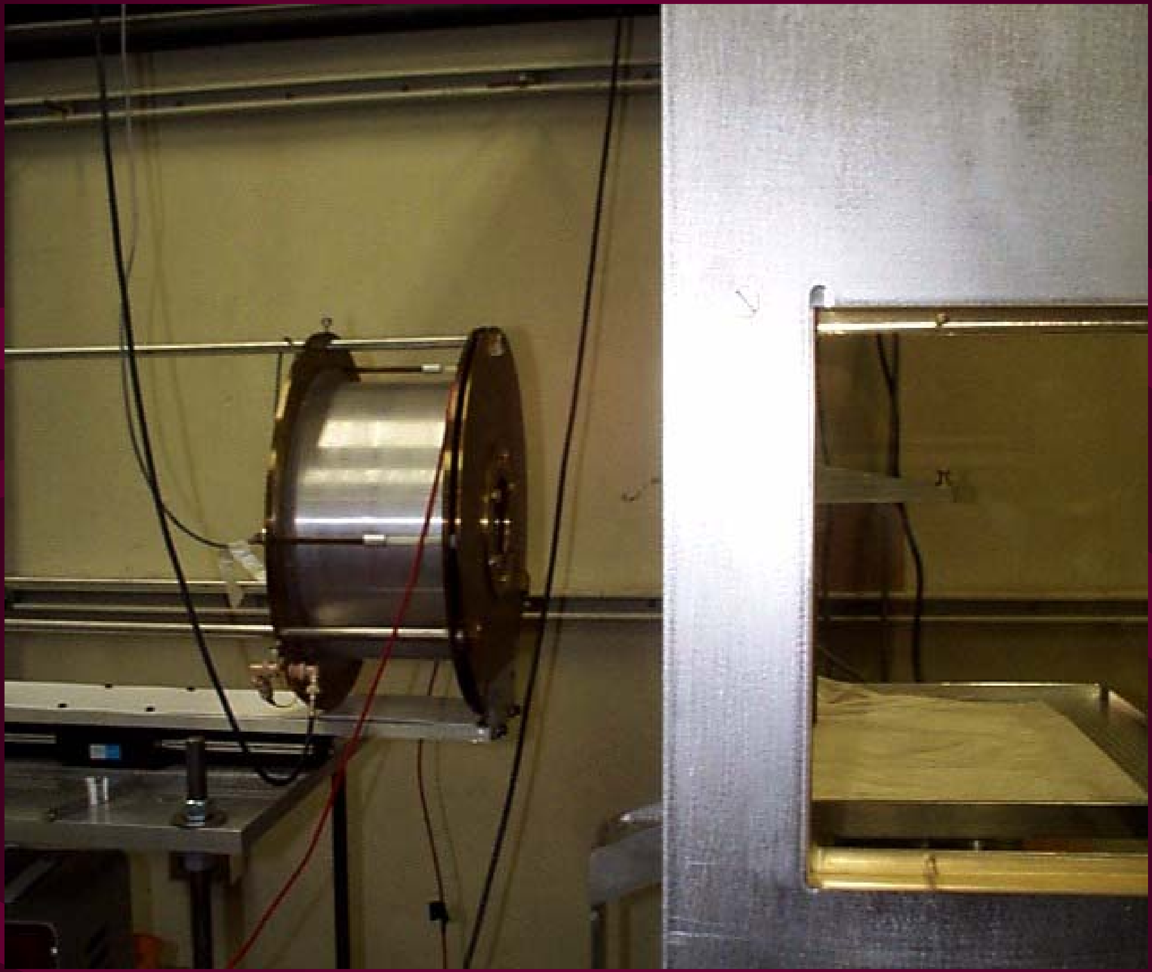
Frequently Asked Questions of the UW ADCL (cont.)

- Similarity in seeds, e.g. why can't they use one manufacturers factor for another manufacturer.
- Confusion on units. "What is air kerma strength"
- What are the appropriate factors: gamma factors, dose rate constants, etc.

NIST Absolute Standards

- Maintained at NIST for various energies
- A free-air chamber used for lower energy photons. Graphite ion chambers used for Ir-192 (1992) and transferred to a well chamber.
- Extrapolation chamber used for beta particles.

NIST Wide Angle Free Air Chamber (WAFAC)



Schematic of WAFAC field

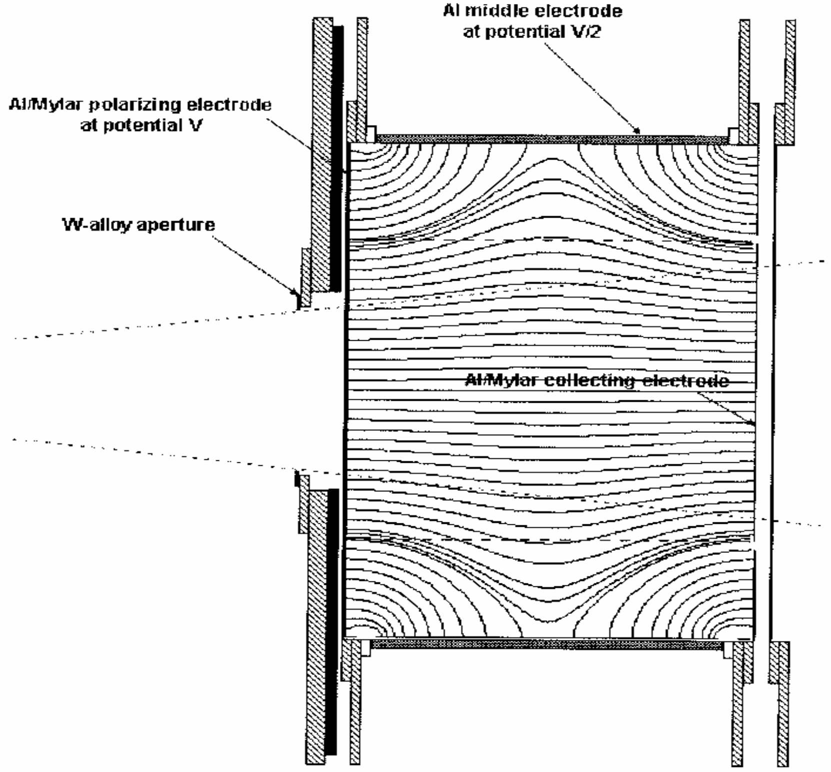


Fig. 4. Schematic diagram of original WAFAC with the long middle electrode, showing the electric field lines. Structures of lead are indicated by black, aluminum by gray, and brass by cross hatching.

History of Low Energy Photon Brachytherapy Sources

- 1993 Loevinger introduces design of Wide-Angle Free-Air Chamber (WAFAC) for low-energy photon seeds. Ti x rays are filtered out.
- 1999 NIST introduces new WAFAC standard for ^{125}I and ^{103}Pd seeds on January 1. Amersham 6711 and 6702 seeds based on measurements made in 1998. Values to ADCL.
- 2000 NIST finds all measurements on seeds in 1999 had about 3% to 6% error. This does not affect Nycomed-Amersham seed calibration.

Apparent Shift in NIST WAFAC Calibrations: 1999/2000

Seed Type	Well-Chamber Calibration Factor Ratio: 1999/2000 (±~2σ)
^{125}I	1.029±0.008
^{125}I on Ag	1.043±0.037
^{103}Pd	1.047±0.016

UW ADCL Observed Change for I-125 seeds

Mfr. And Model	% Change in CF	Date of Calibration
NAS 3631A/M	-2.4 %	Aug 22, 2000
Best 2301	-3.3 %	Aug 18, 2000 (Best 10/9/00)
Mills 125SH	-8.6 %	Sept 14, 2000
Syncor Pharm.	-4.4 %	Sept 5, 2000
Draximage LS-1	-6.3 % -9.2% -9.7%	Sept 11, 2000 Oct 7, 2000 Jan 13, 2001

UW ADCL Consistency Data with Nycomed-Amersham

- UW calibrated 22 6711 seeds between August 27, 1998 through June 26, 2000
- Average Ratio of calibrated seeds for Amersham/UWADCL is 1.007 ± 1.3%
- NIST calibrations were in error by 3% to 4% in 1999; this was observed by Mfr. And seeds sent to ADCL

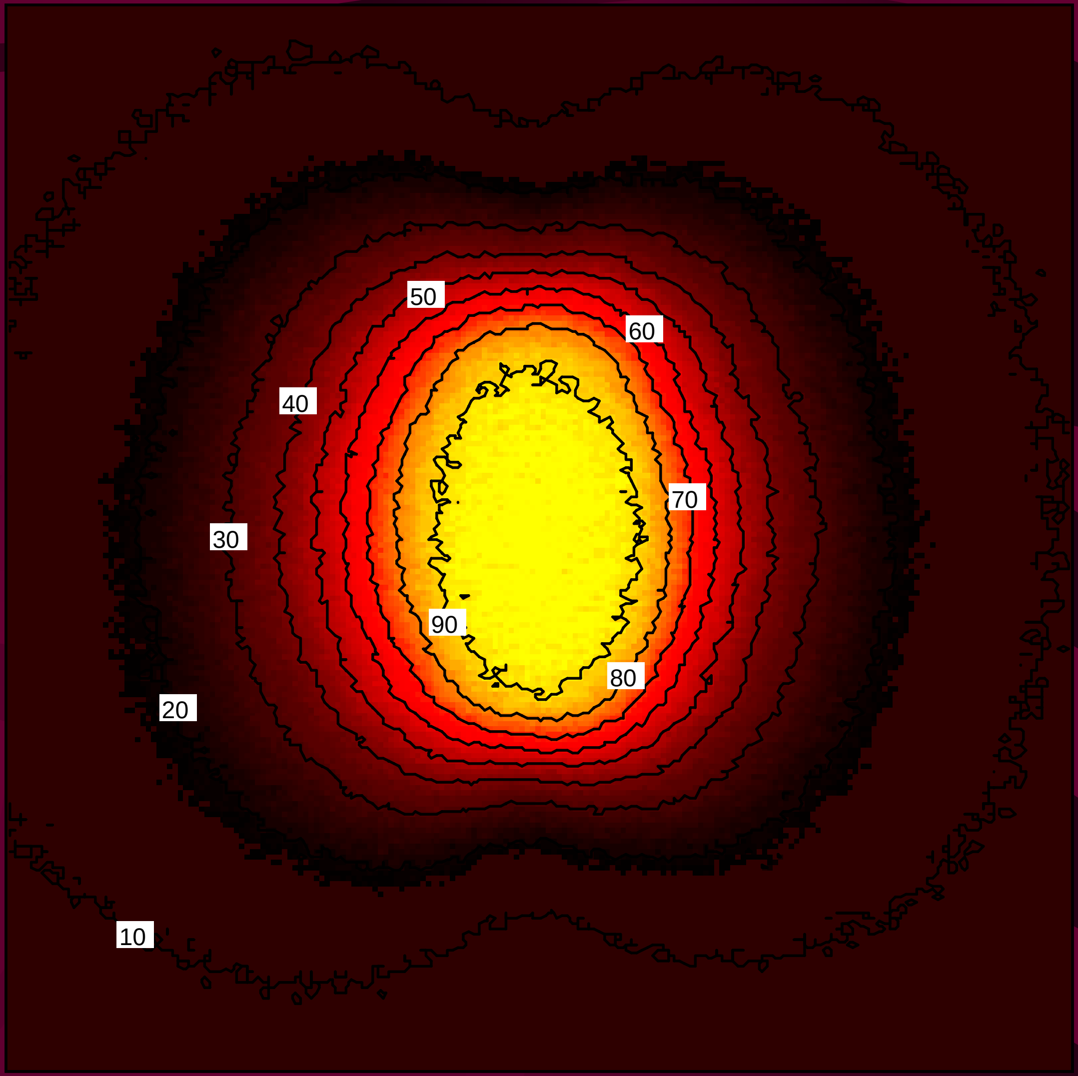
U W ADCL Observed Change for Pd-103 seeds

Mfr. & Model	% Change in CF	Date of Calibration
NAS MED3633	-4.5 %	Aug 22, 2000
Theragenics Thera200	-4.2 % -7.5%	July 8, 2000 Oct. 2000
Int Brachy 1031L	-6.1 %	July 16, 2000
Best 2335	-6.5 %	Sept 2, 2000

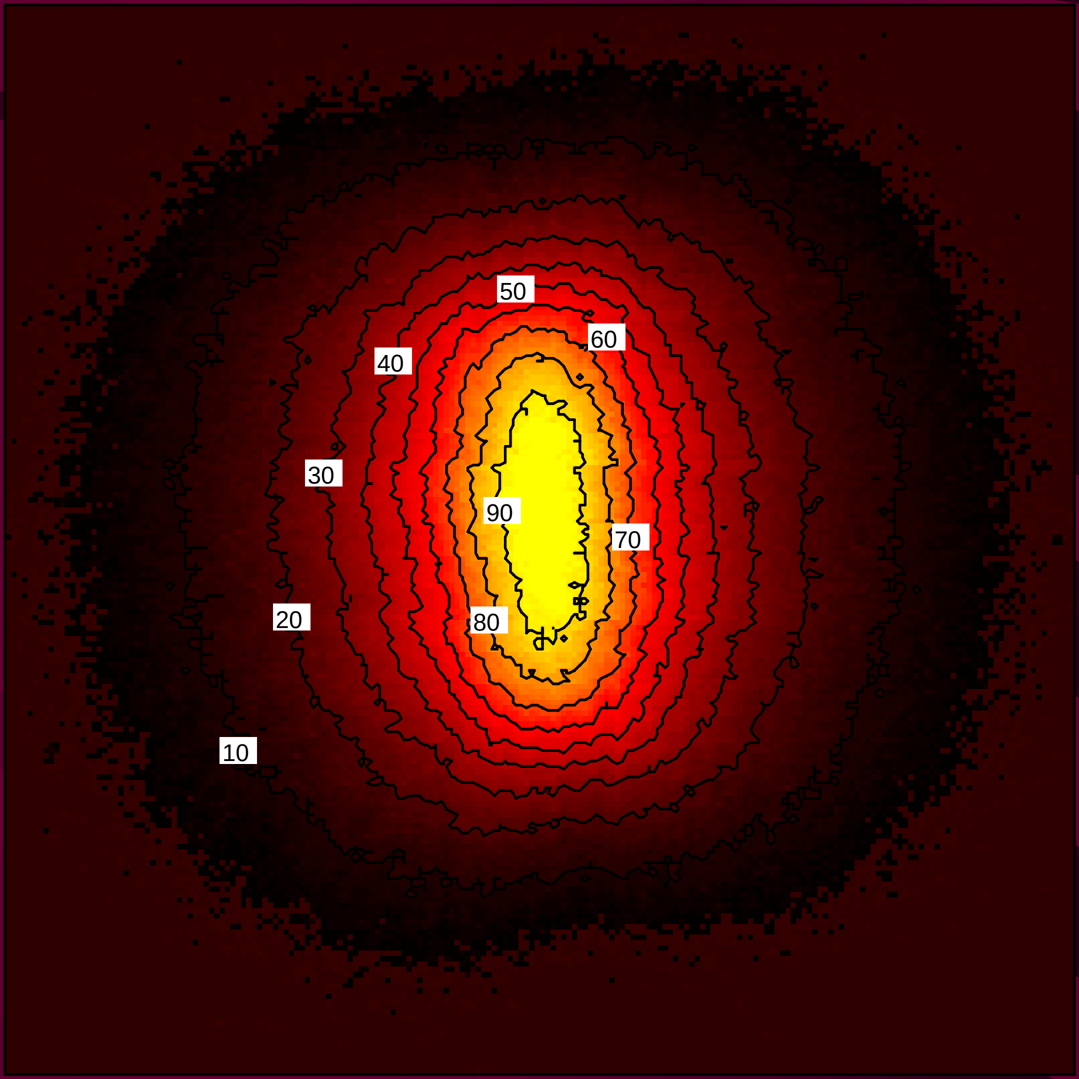
I-125 and Pd-103 Brachytherapy LDR Source Calibration

- New NIST-2000 air kerma strength calibration factors have been established at the UW-ADCL for fourteen I-125 and five Pd–103 source models - seeds are different
- A NIST calibration date is listed for all seeds.
- Uniformity is checked periodically for all seeds

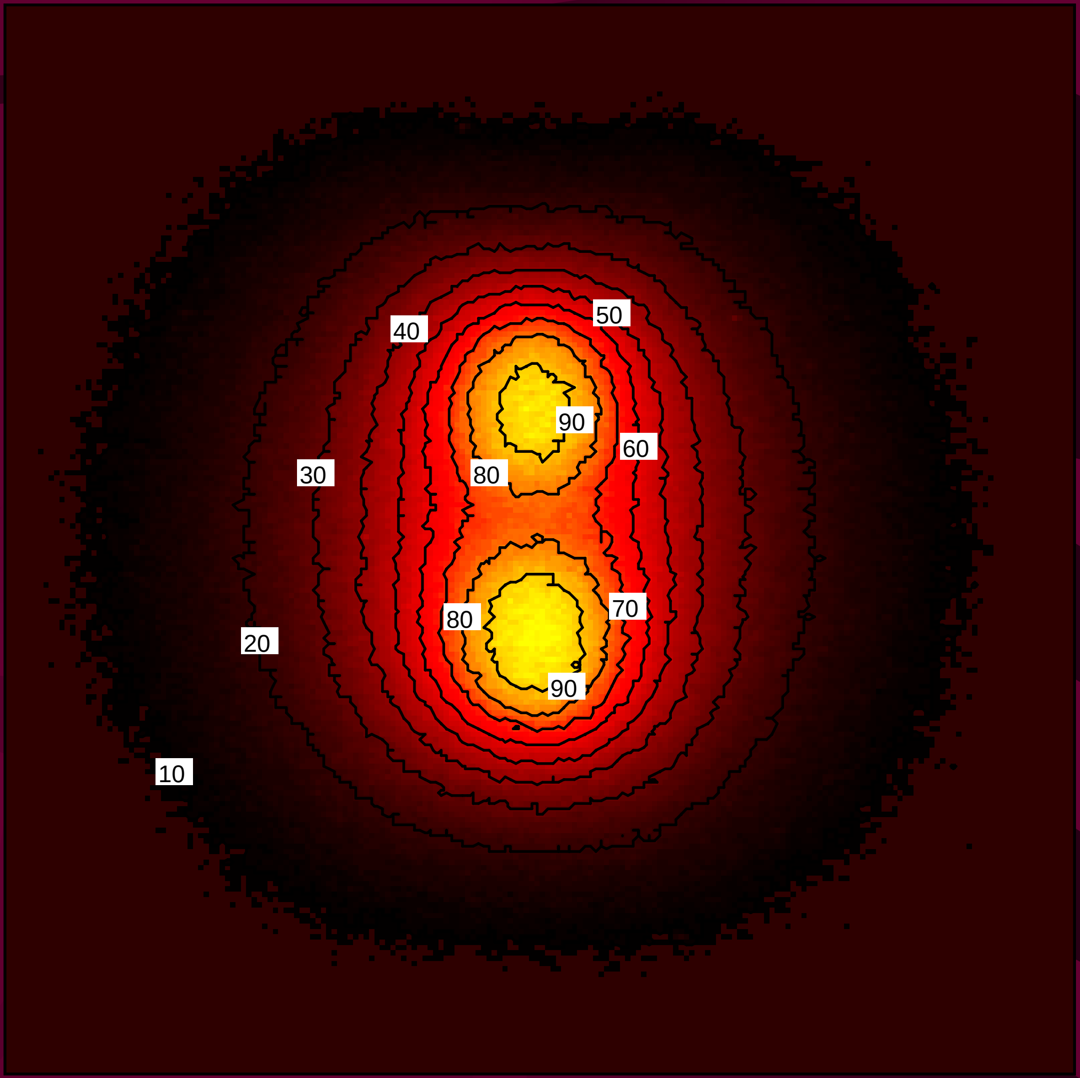
Example of a color enhanced surface contour plot of a Nycomed Amersham model 6711 I-125 source on contact with Kodak XV film.



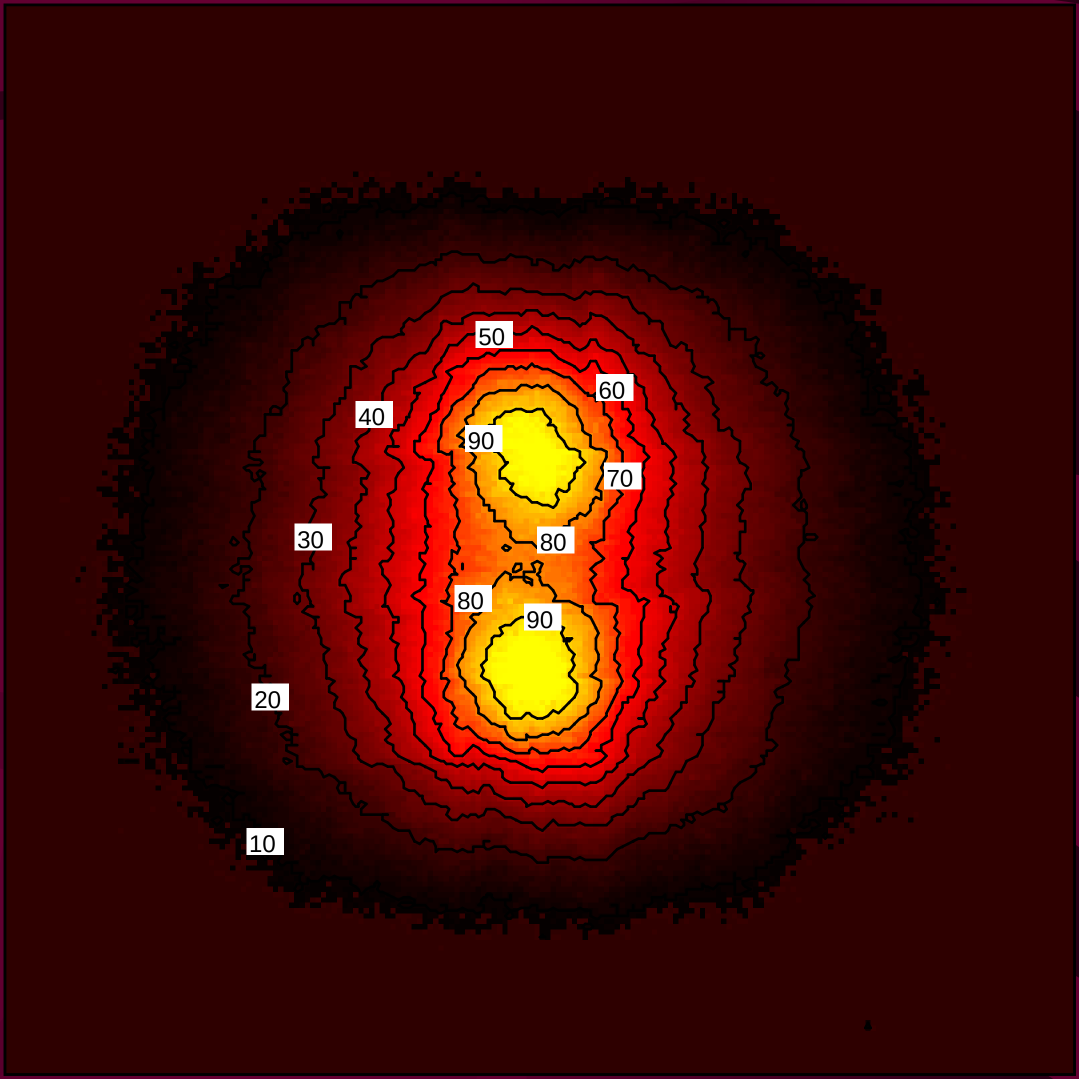
Example of a color enhanced surface contour plot of a Bebig Uromed model Symmetra I-125 source on contact with Kodak XV film.



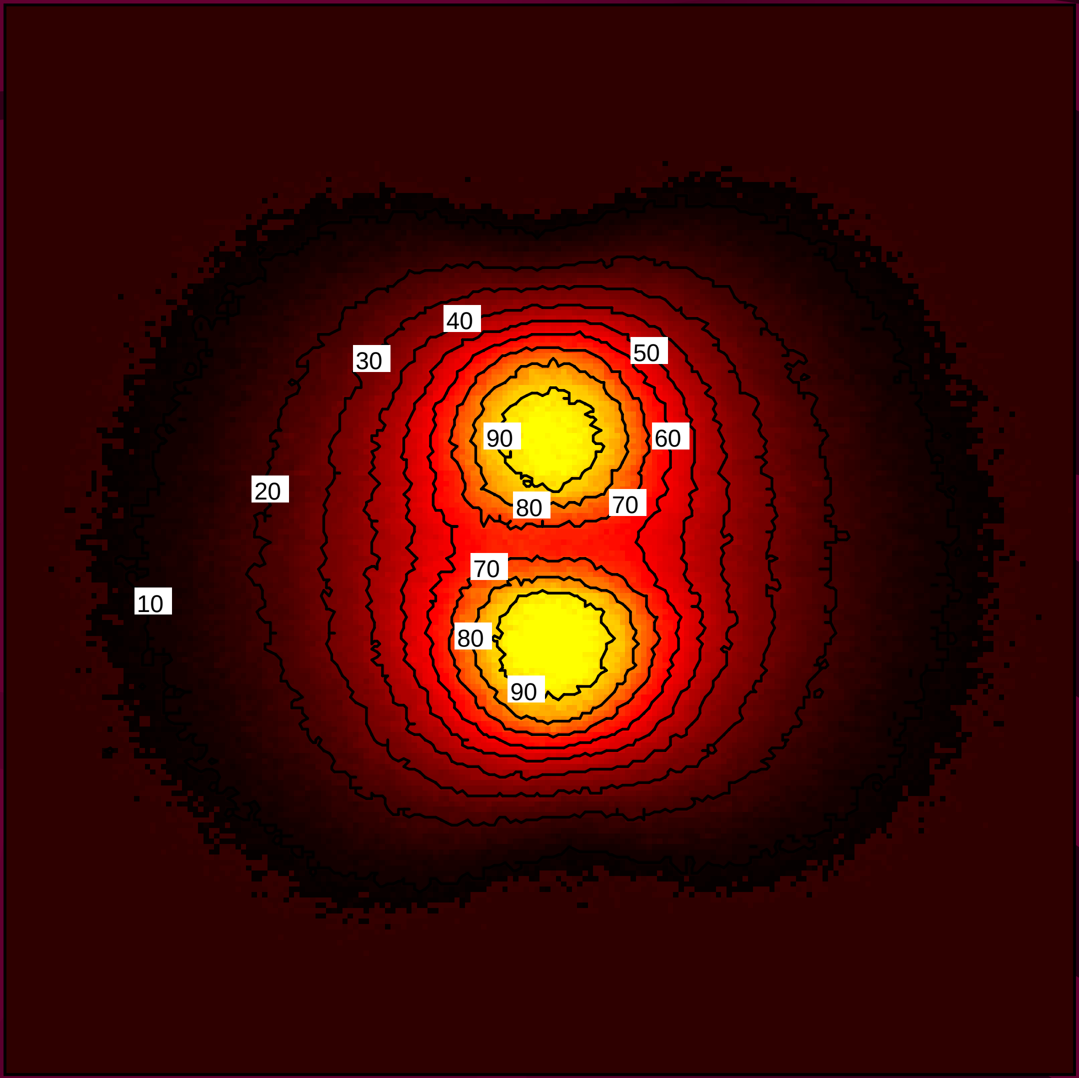
Example of a color enhanced surface contour plot of a N.A.S. Mentor model 3631A/M (IoGold) I-125 source on contact with Kodak XV film.



Example of a color enhanced surface contour plot of a N.A.S. Mentor model MED3633 (PdGold) Pd-103 source on contact with Kodak XV film.



Example of a color enhanced surface contour plot of a Theragenics model Theraseed 200 Pd-103 source on contact with Kodak XV film.



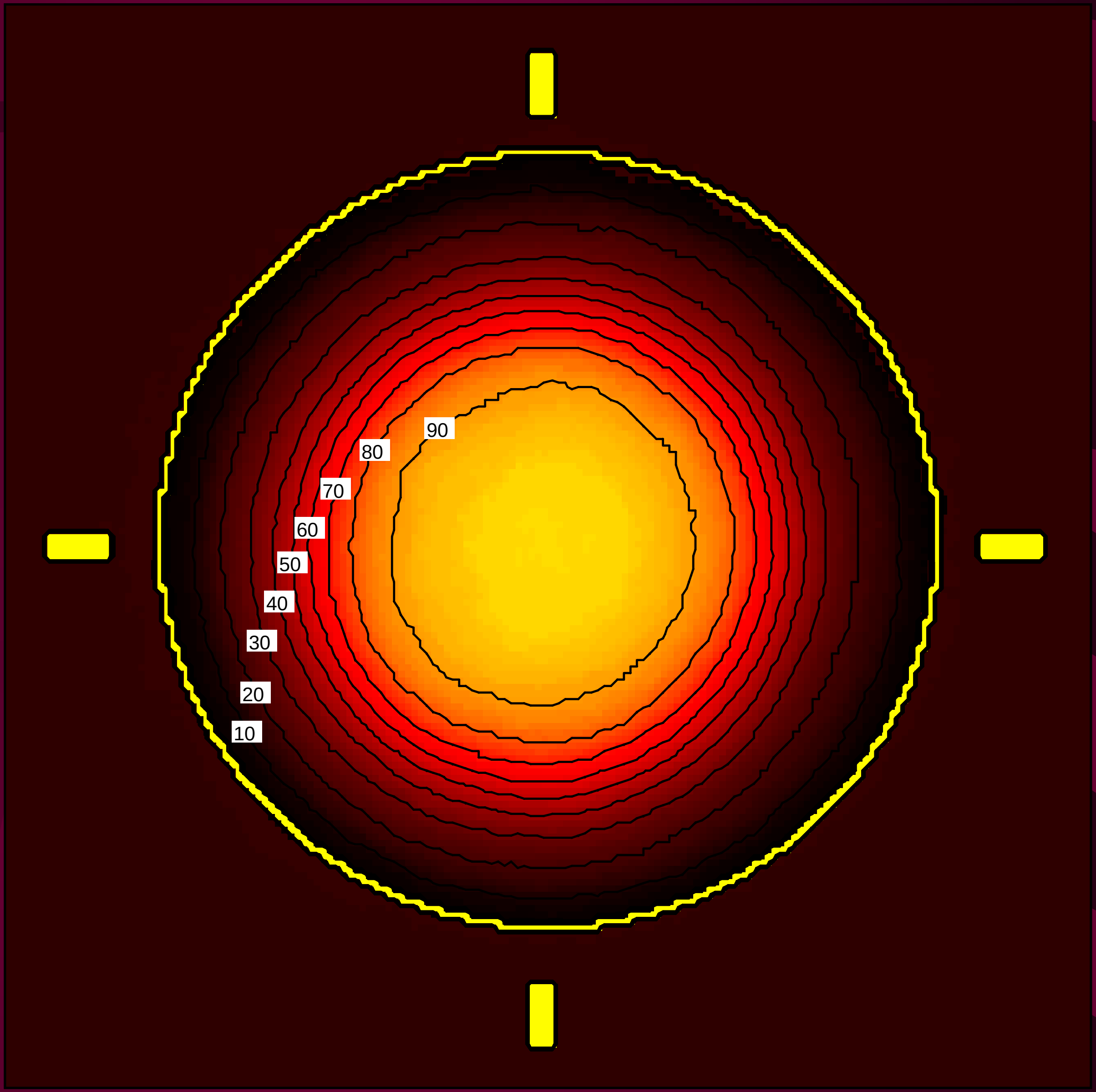
Beta Particle Calibrations

- There are two distances used for calibration
  - Since betas are so readily absorbed in tissue, absorbed dose in water at 2 mm depth with an extrapolation chamber has been used.
  - An extrapolation chamber has been used to calibrate to the surface of the source

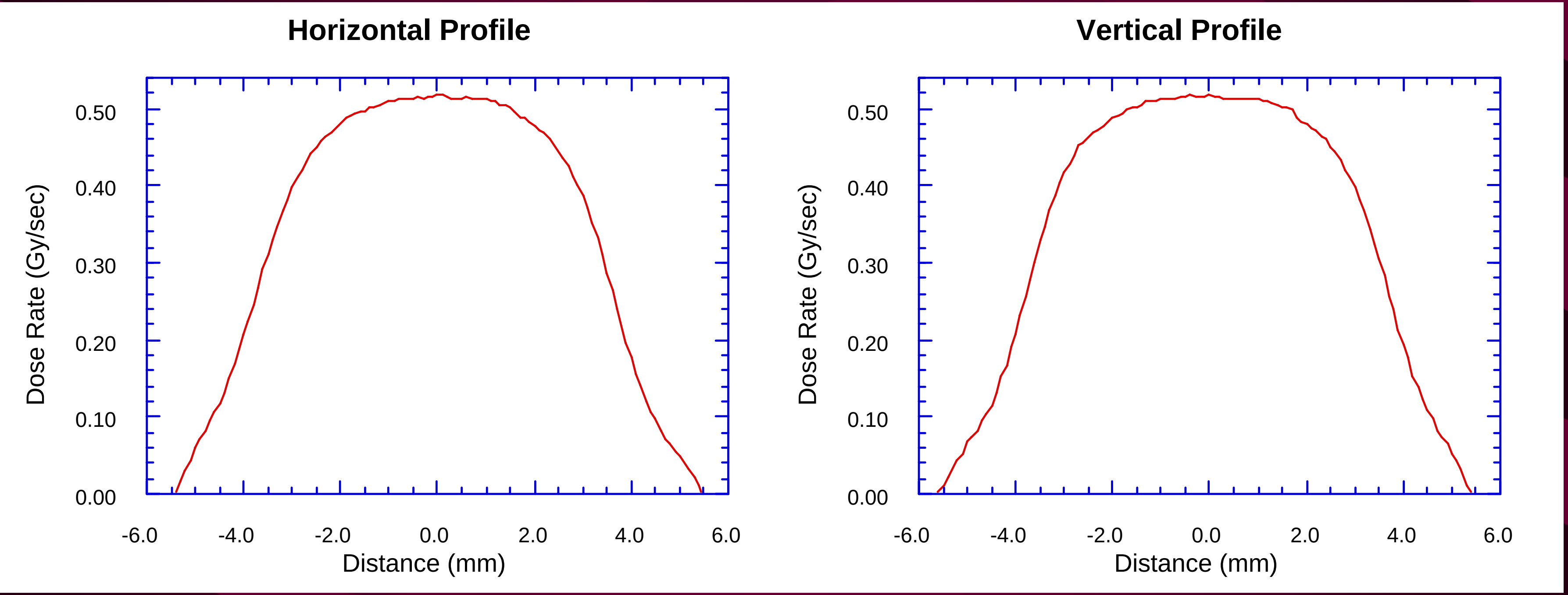
ADCL Sr-90 Ophthalmic Applicator Calibration with Radiochromic Film

NIST traceable determination of the absorbed dose to water rate in the central 4 mm of the applicator including color enhanced contour plots and two dimensional dose profiles.

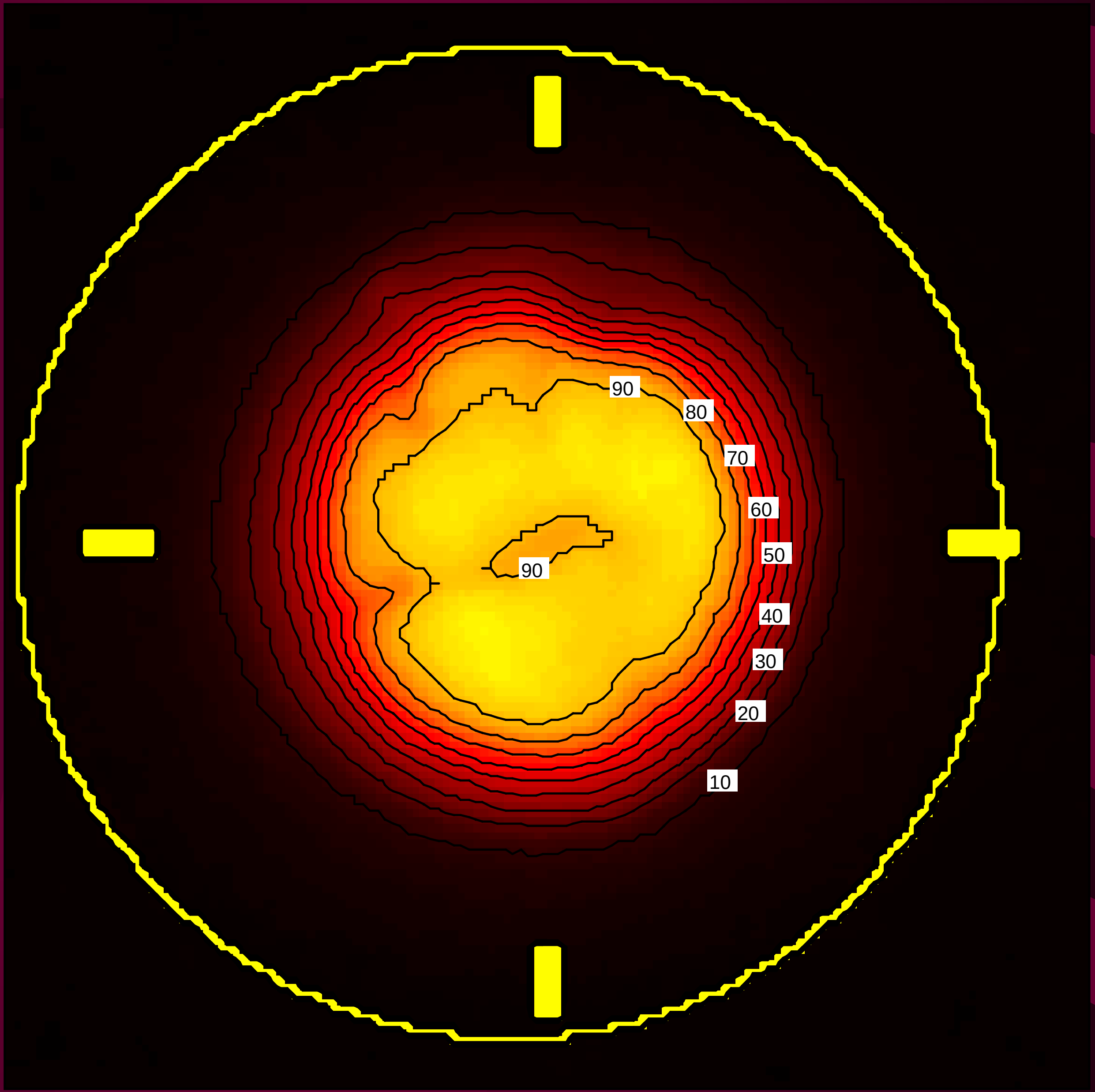
Example of a color enhanced contour plot of a uniform Sr-90 ophthalmic applicator. The dose weighted isocenter is equidistant from the hash marks. The outer circle represents the source physical diameter.



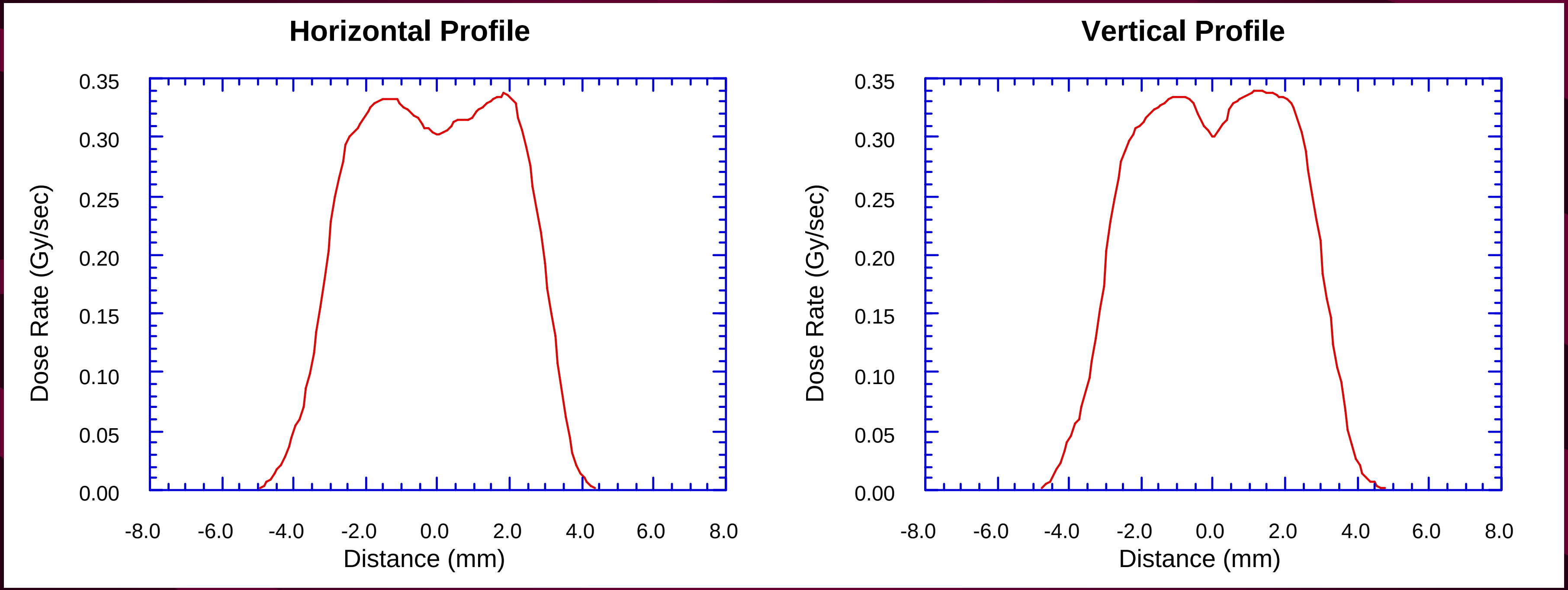
2-Dimensional dose profiles for a uniform source.



Example of a color enhanced contour plot of a *non*-uniform Sr-90 ophthalmic applicator. Notice the offset or shift of the dose weighted isocenter from the physical source center, and the non-uniform dose distribution.

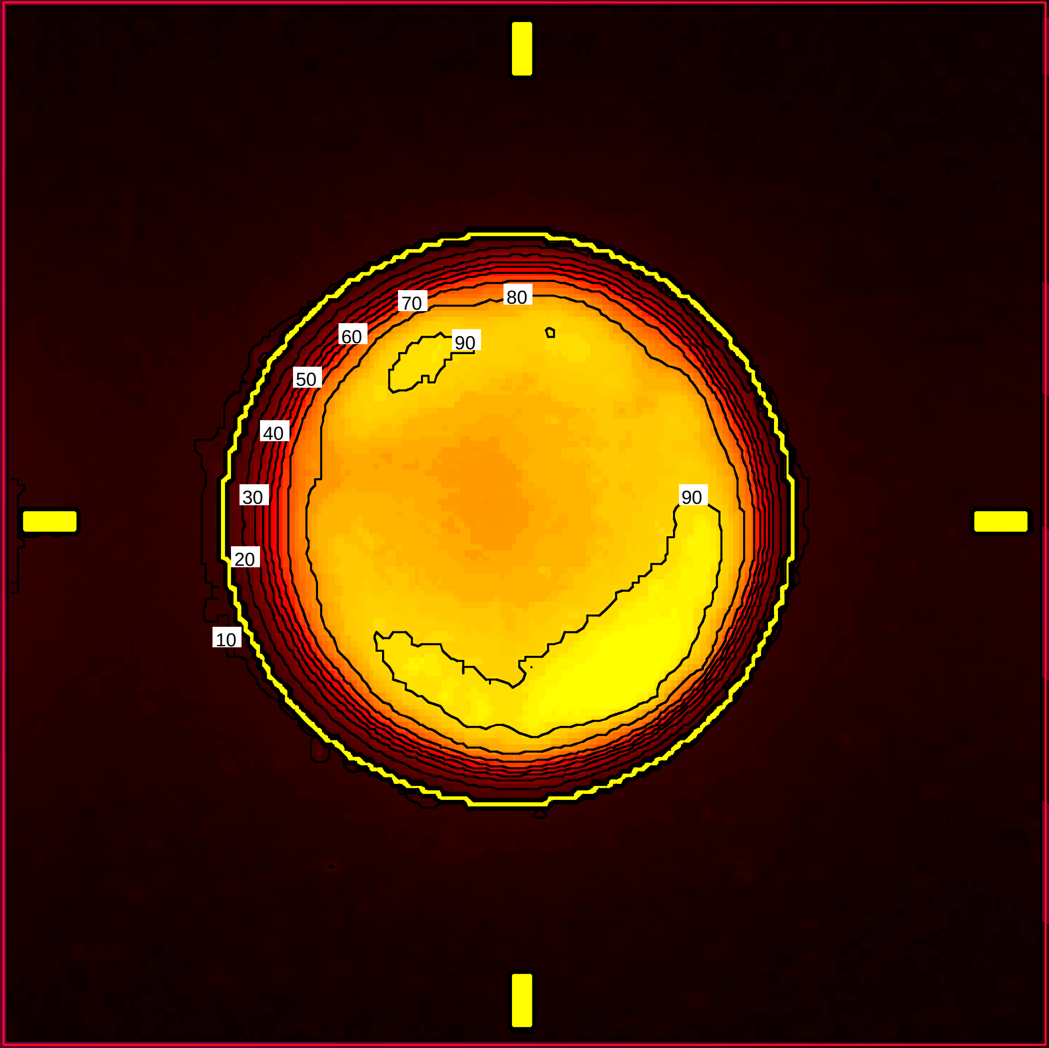


2-Dimensional dose profiles for a *non*-uniform source.

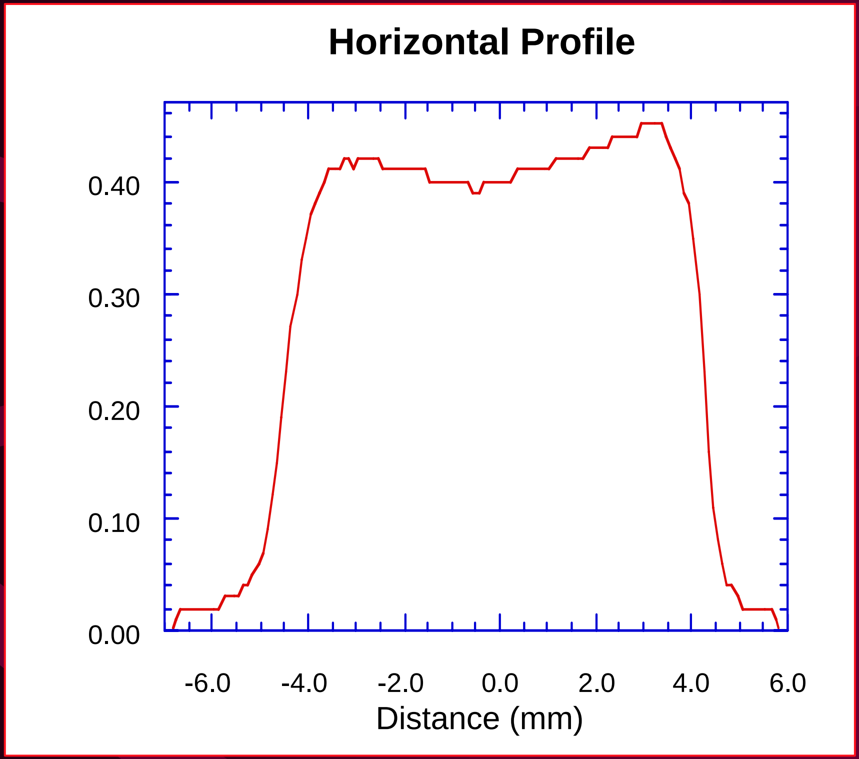


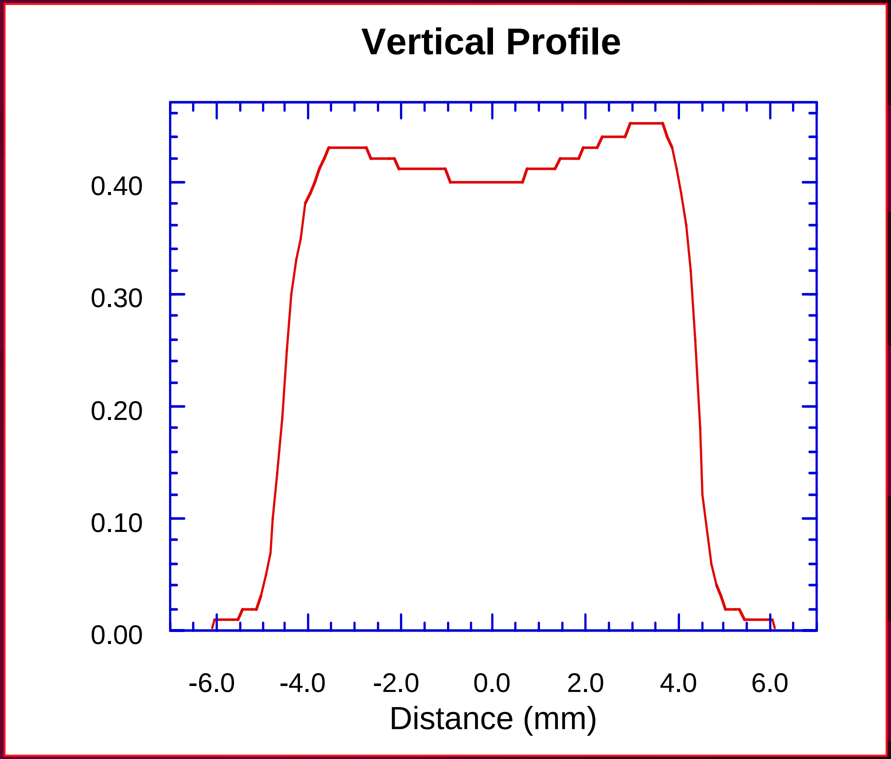
Skewed Dose Sr-90 Source

Example of a color enhanced contour plot of a *skewed*-Sr-90 ophthalmic applicator. Notice the offset or shift of the dose weighted isocenter from the physical source center, and the non-uniform dose distribution.



2-Dimensional dose profiles for a *skewed* source.





Types of IVBT Sources once upon a time - ADCL standards

- High energy photon sources (^{192}Ir). Generally in a seed train up to approximately 23 seeds.
- Beta brachytherapy sources.

➲ ^{90}Sr in a seed train, presently 30 mm, 40 mm and 60mm long from Novoste in 5.0 French and 3.5 French catheters

➲ ^{32}P source from Guidant

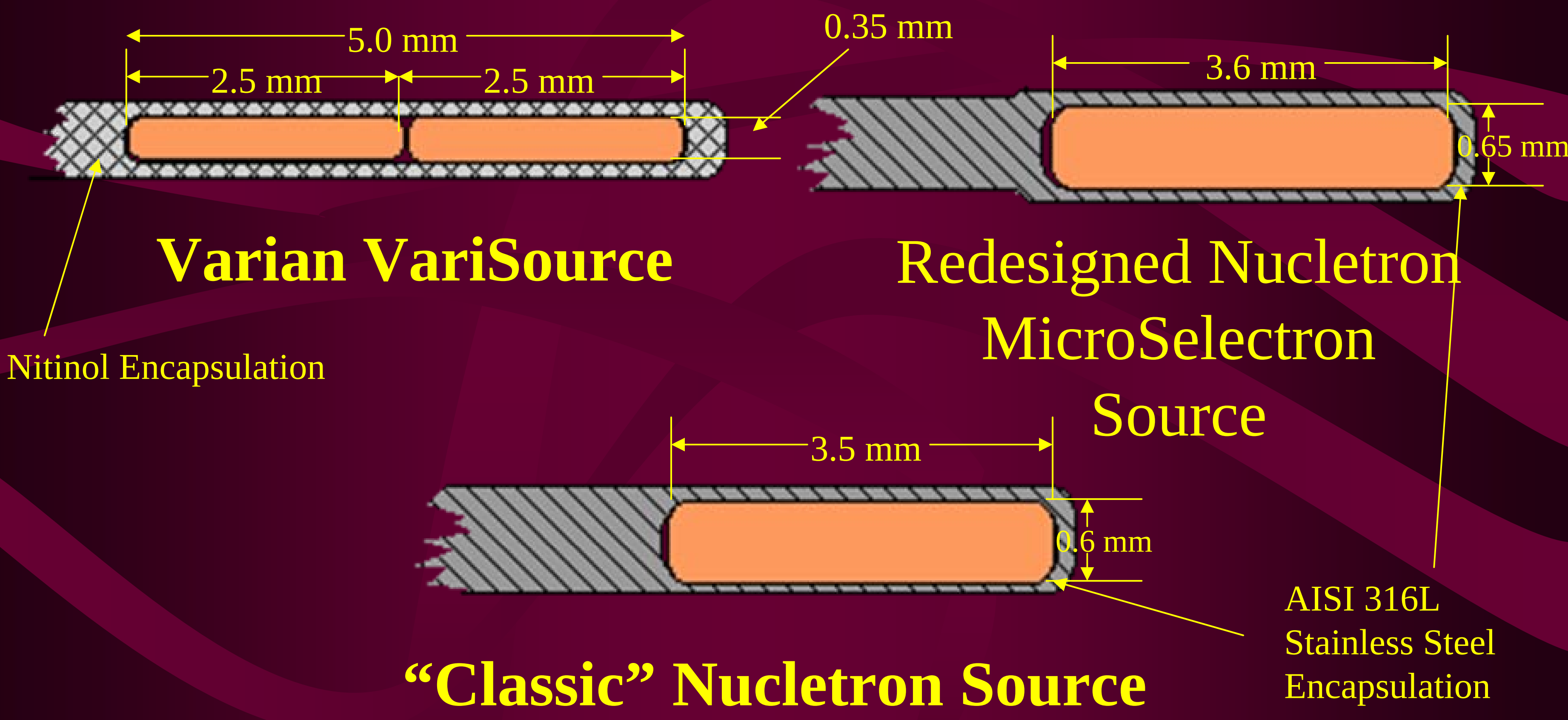
Calibration of ^{192}Ir HDR Sources

- NIST does not offer a primary HDR ^{192}Ir source calibration
- 7-Distance in-air technique first proposed at the University of Wisconsin by Goetsch *et al*. in 1991
- Allows ADCLs to provide NIST traceable calibrations for HDR ^{192}Ir
- NIST traceability is provided by an interpolated chamber correction factor

7-Distance In-Air Technique

- Measures the output of the source at seven source-to-chamber distances
- UWADCL measurement was originally based on the “Classic” Nucletron HDR source
- Measurements were made to compare the new Nucletron and Varian sources with the old “Classic” source.

HDR Sources


5.0 mm
2.5 mm
2.5 mm
0.35 mm
3.6 mm
0.65 mm
Varian VariSource
Nitinol Encapsulation
Redesigned Nucletron MicroSelectron Source
3.5 mm
0.6 mm
AISI 316L Stainless Steel Encapsulation
“Classic” Nucletron Source

Results of the 7-Distance Measurement

Source Type	*7-Distance Result ($mGy\ m^2\ hr^{-1}$)*	*Well Chamber Result ($mGy\ m^2\ hr^{-1}$)*	*Percent Difference*
Redesigned Nucletron MicroSelectron	17.87	17.87	+0.00
	33.33	33.30	+0.09
	26.20	26.09	+0.42
	26.02	26.09	-0.27
	26.07	26.09	-0.08
	26.03	26.09	-0.23
	25.95	26.09	-0.54
Average Percent Difference			-0.09 +/- 0.30

Results of the 7-Distance Measurement

Source Type	*7-Distance Result ($mGy\ m^2\ hr^{-1}$)*	*Well Chamber Result ($mGy\ m^2\ hr^{-1}$)*	*Percent Difference*
Varian VariSource	29.67	29.88	-0.70
	25.58	28.78	-0.69
	28.12	28.24	-0.42
	27.89	27.98	-0.32
Average Percent Difference			-0.53 +/- 0.19

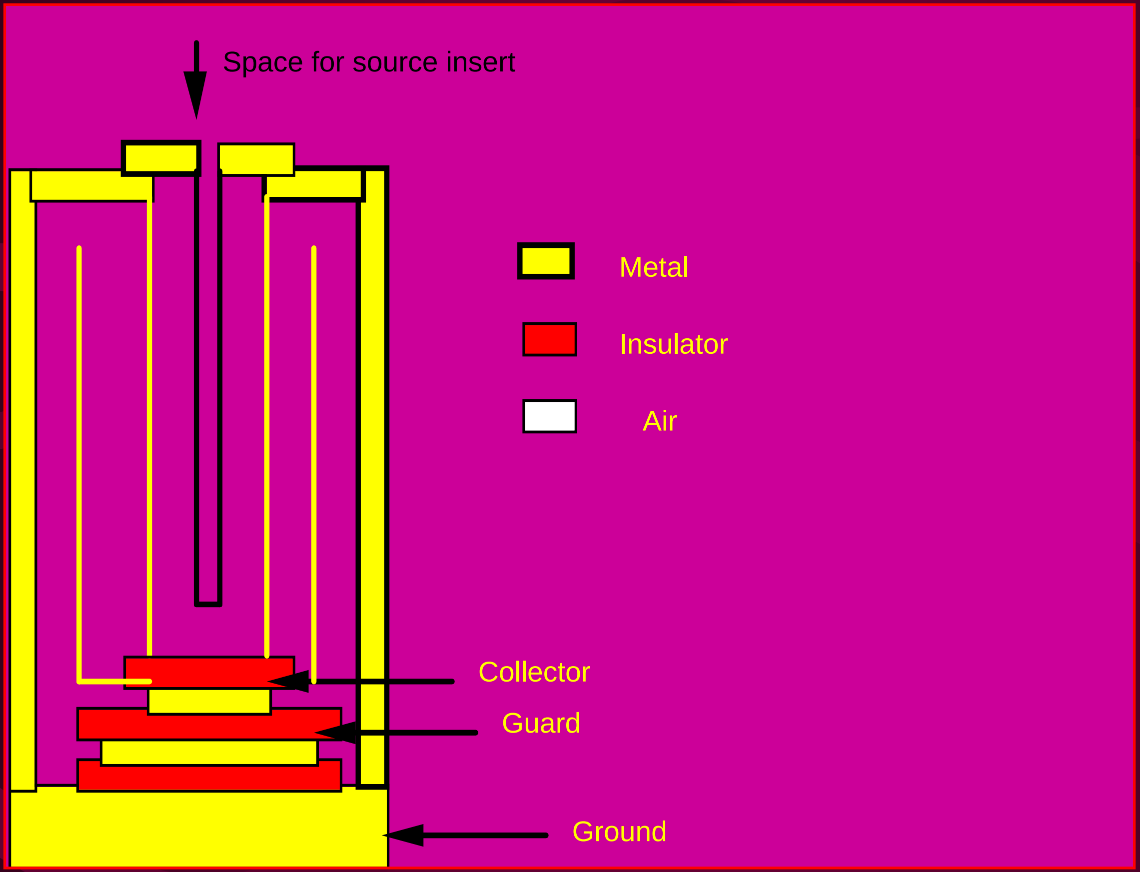
Conclusions HDR Sources

- Both the VariSource and redesigned MicroSelectron source fall within the expressed uncertainty of the 7-distance calibration
- The measured Air Kerma Strengths of both new sources are within 1% of each other
- The new sources and the 1991 standard calibrations all lie within the 2σ uncertainty of the measurement
- The result of the uncertainty analysis (2σ=2.14%) is in good agreement with the previous uncertainty estimate (2σ=2%)

Clinical Measurement

- **Well chambers calibrated at an ADCL can be used to measure LDR, HDR or beta sources (not ophthalmic applicators)**

Schematic of Well Chamber



Chamber Example

- Note insert allowing for differing length trains.
- The insert is an important part of the calibration.

Well chamber

- Repeating measurements of same source give deviations for all manufacturers of ^{125}I sources <1%
- Repeating measurements of same source give deviations for all manufacturers of ^{103}Pd sources <1.5%

Disadvantages of Nuclear Medicine Chambers

- Generally measure only in activity
- Generally have settings for given radionuclides but not brachytherapy sources
- Precision may not be as good, gas leakage

Disadvantages of Nuclear Medicine Chambers (cont.)

- If therapy physicist does not have control, the general use of the Nuclear Medicine Chamber may result in contamination from nuclear medicine sources.
- Walls may absorb the radiation you want to measure - also energy dependence.

Clinical Calibration of Brachytherapy Sources

- **ADCL Calibrated Well chamber: Provides the most convenient, accurate and precise measure of source strength.**
- **Single seed source calibration: Used to transfer calibration to a clinical well chamber.**

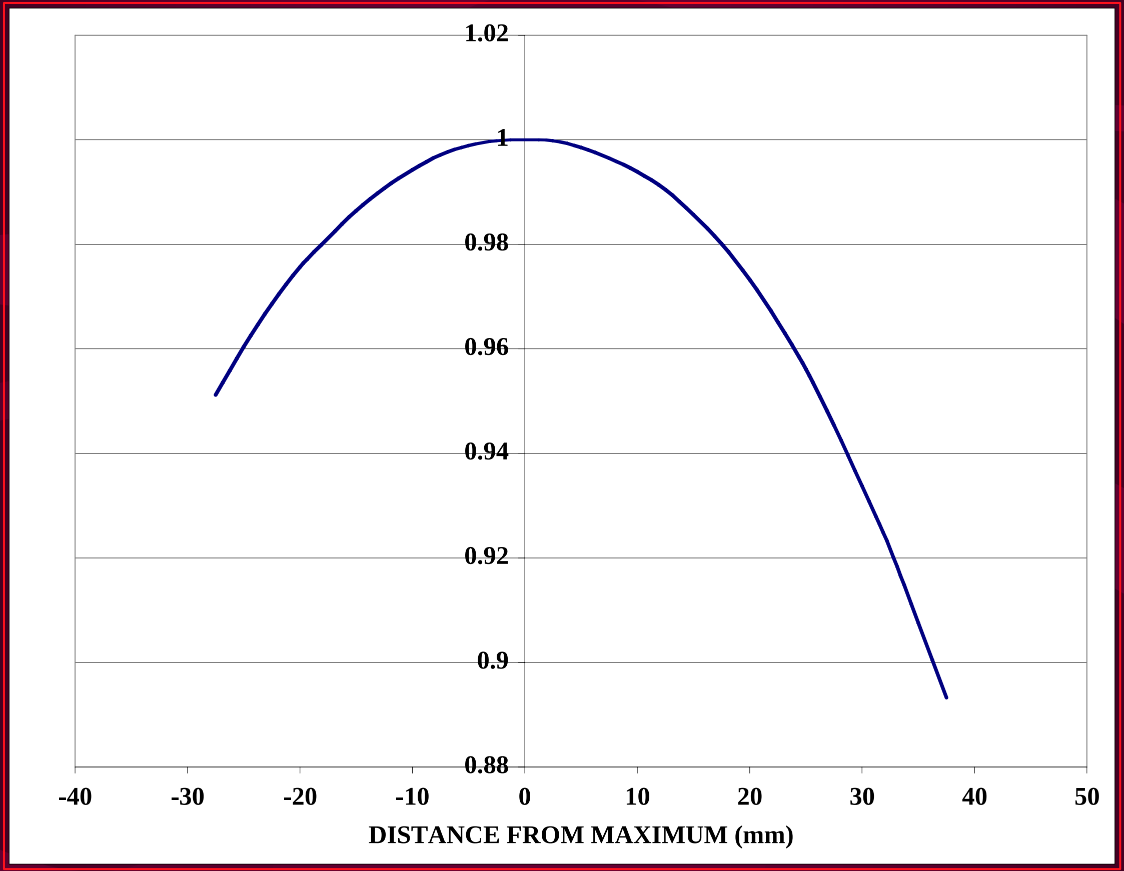
Items to Maintain Well Chambers

- Set up a QA check, using another known source: Cs needle, cobalt unit, accelerator, or redundancy for a number of chambers
- Account for any leakage if it is significant. Keep in mind that there may be other sources contributing to background that could look like leakage.

Characteristics of Well Chambers

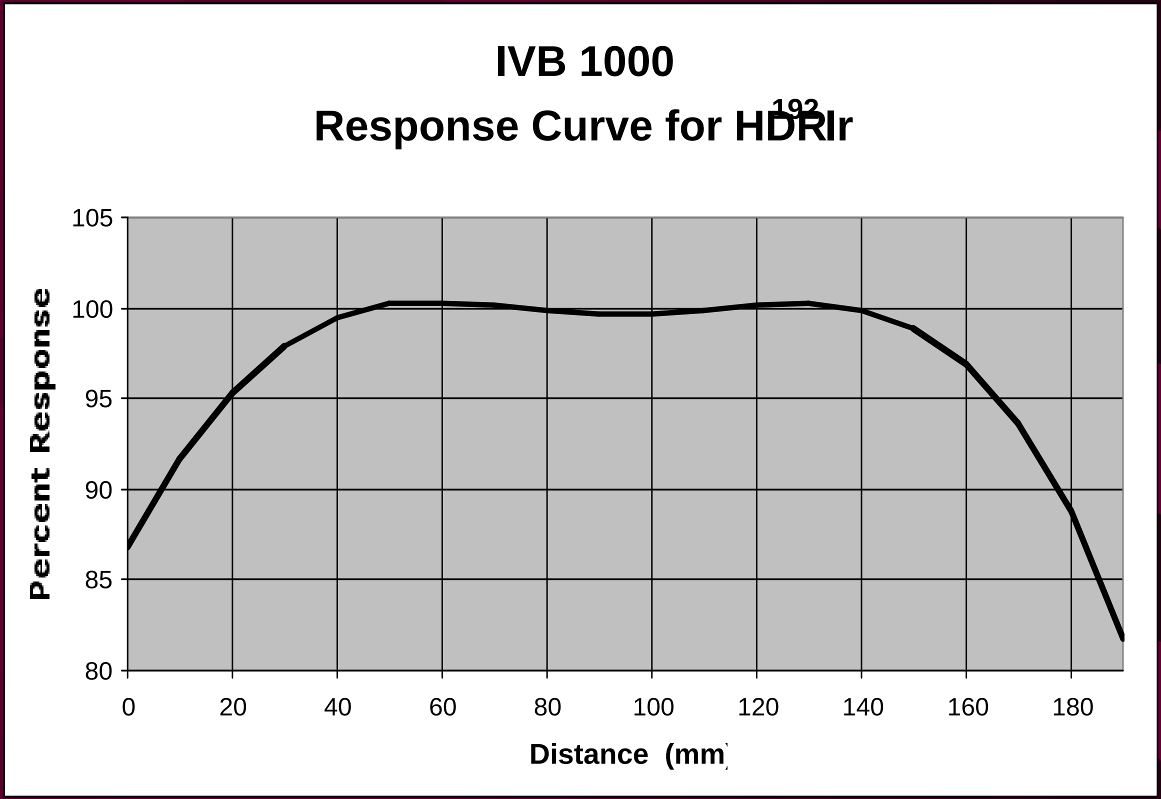
- Typically calibration of well chambers involve using a single seed at the axial maximum (sweet spot)
- Problem with trains is “fall off” of the “sweet spot” of well chambers due to axial geometry limitations and the effect this has on various lengths of source trains.
- Manufacturers made modifications to obtain extended “sweet length”

Response with Length for a Well Chamber



Measurements of Axial Sweet Spot of IVB 1000

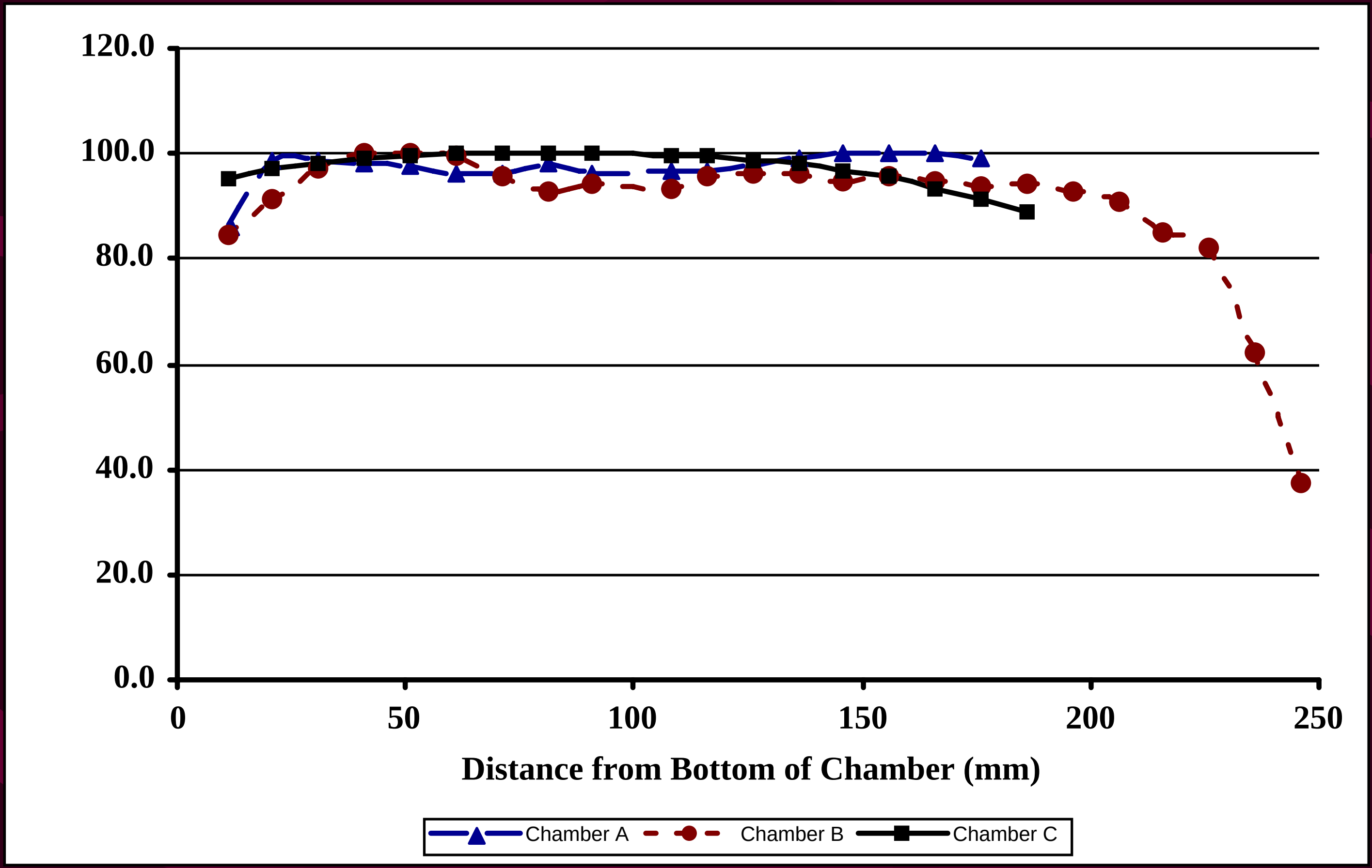
An HDR ^{192}Ir source was used to allow high precision scanning of chamber axial response.



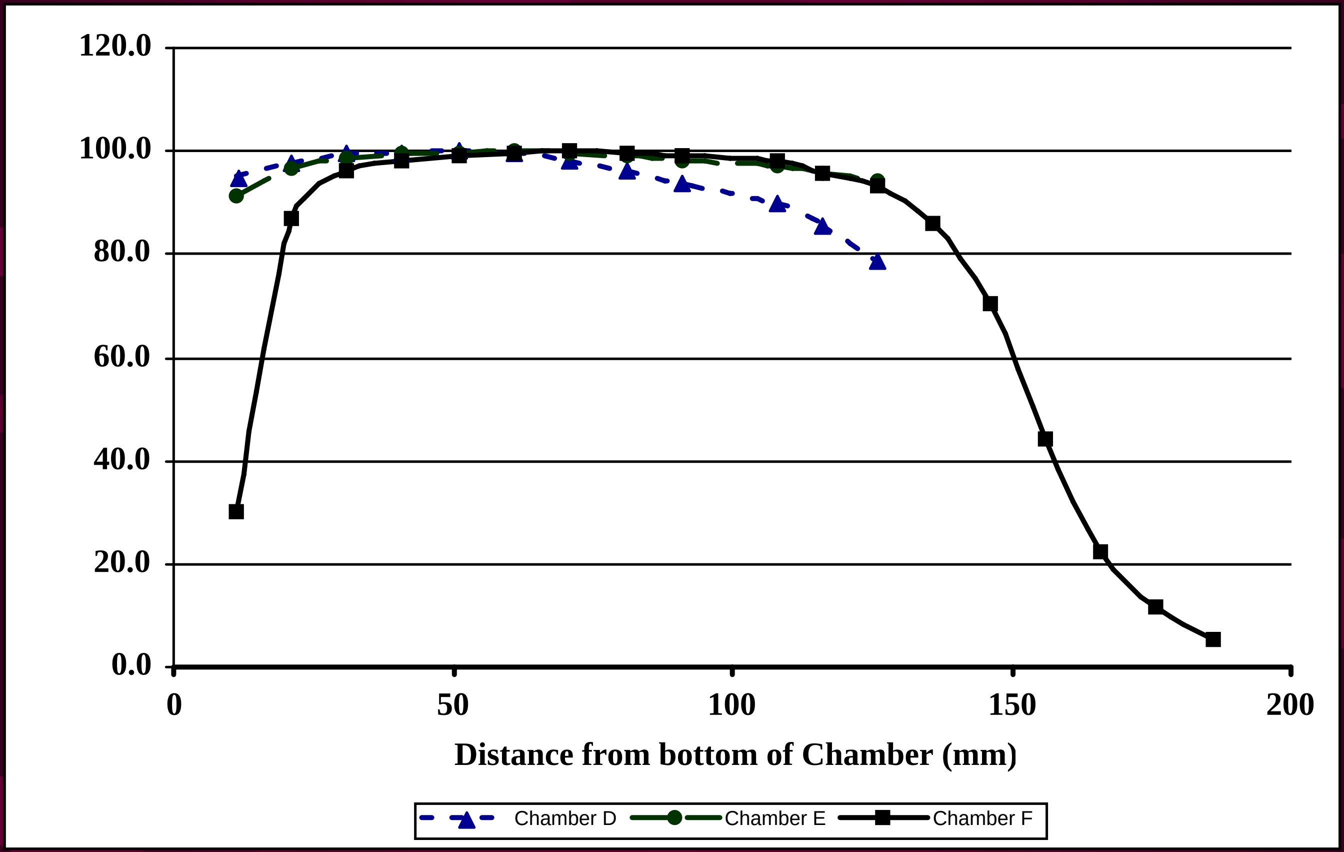
Well Chamber Responses

- Single seed (photon and beta particles) used to measure sweet length of all chambers.
- Sweet length for beta particles similar to photons.
- Long sweet length chambers have a flat response area (sweet length) of approximately 100 mm
- Short sweet length chambers have a flat response area of approximately 40 mm

Axial Sweet length (long)



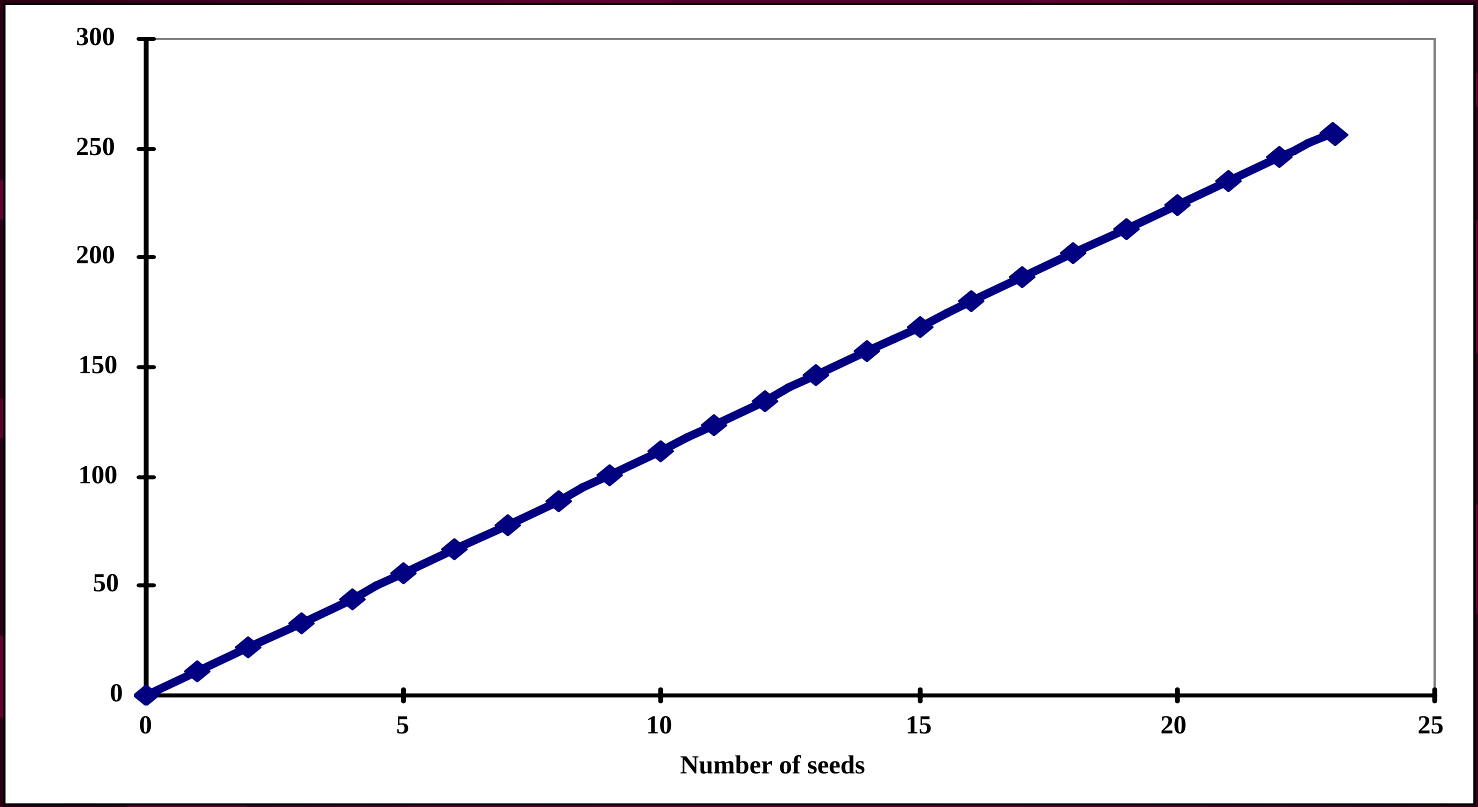
Axial Sweet Length (short)



Measurement of source trains

- Source trains of any type can be measured in chambers with a large enough sweet, length.

Air kerma strength versus number of seeds



Conclusion of train measurements

- Single seed calibration factor used for trains is valid within the calibration uncertainty of 2.5%.
- Measurements can be made for the train of seeds with a precision of $\pm$0.3%.
- Short term reproducibility (removing source and replacing) was within 0.05%.

ADCL Provided Quantities from Calibration

- Position of Calibration
- Air kerma calibration factor for the well chamber
- Calibration factor for the electrometer scale
- Correction for collection efficiency at time of calibration

Clinical HDR measures

- Use a well chamber calibrated from an ADCL
- N_{Sk} is used in clinic to give S_k

$S_k = Rdg*N_{sk} *C_e * C_{tp}$

Where Rdg is the electrometer reading in amperes

N_{sk} is the calibration factor provided by the ADCL (U/A)

C_e is the electrometer scale correction factor

C_{tp} is the air density correction factor (if needed)

Calibration of Beta sources for Intravascular Use

- **ADCL will calibrate a well ionization chamber to absorbed dose at 2mm water.**
- **Question is are the calibrations of the 40 mm train and 60 mm train related to that of the 30 mm train.**

Well chamber calibrations for beta sources

- UW ADCL has shown that can calibrate a 30 mm train, then the following is true for some well chambers
  - $N_{40} = 0.75\ N_{30}$ and
  - $N_{60} = 0.50\ N_{30}$

UWADCL Well Chamber Rejection Criteria for IVBT

- Inadequate Axial Sweet Length for Measurement of Line Source or Trains
- Low Signal-to-Noise Response
- Non-Uniform Collecting Volume or Wall Geometry especially for beta particles
- Lack of Appropriate Source Holder Apparatus or Reproducible Geometry
- Manufacturer Restriction on Use

Clinical measurement of a photon source

- Equation for determination of air kerma strength S_k is:

$$S_k = Rdg * N_{sk} * C_e * C_{tp}$$

Where Rdg is the electrometer reading in amperes

N_{sk} is the single seed calibration factor provided by the ADCL (U/A)

C_e is the electrometer scale correction factor

C_{tp} is the air density correction factor (if needed)

- If average strength per seed is needed, the total train air kerma strength is divided by the number of seeds.

Clinical measurement of a source train (beta)

- Equation for determination of absorbed dose to water at 2 mm, D_{2mm} is:

  $D_{2mm} = Rdg * N_{2mm} * C_e * C_{tp}$

Where Rdg is the electrometer reading in amperes

N_{2mm} is the calibration factor provided by the ADCL (either for appropriate length source or with a correction factor from 30 mm source train

C_e is the electrometer scale correction factor

C_{tp} is the air density correction factor (if needed).

Clinical Measurement Problems and Misunderstandings

- Uncalibrated instrumentation
- Instrument malfunction or operator error
- Improper use of instrumentation
  - Inappropriate measurement geometry
  - Low Signal to Noise Ratio
- Lack of understanding
  - Misunderstanding of ADCL calibration and AAPM recommended protocols
  - Confusion from manufacturer certificates

Cautions

- Manufacturer not as precise.
- Pharmaceutical companies loading needles, saying they have measured the seeds. Caution, how do you know? Are you the physicist who is responsible for what the patient gets?

Meaning to the Physicist?

- Know details of sources. Don’t change anything without clear understanding!
- Trust your calibrated well chamber (or “Mfr” if you know what value is being used)
- Use consensus dose rate constant related to date of calibration

Conclusion

- Use of calibrated well chamber allows easy calibration for sources.
- A calibration factor is necessary for each source type to be calibrated
- Measurement of air kerma strength or absorbed dose to water at 2 mm
- This results in confidence in brachytherapy dosimetry