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Clinical LDR prostate brachytherapy uncertainties from seed construction parameters

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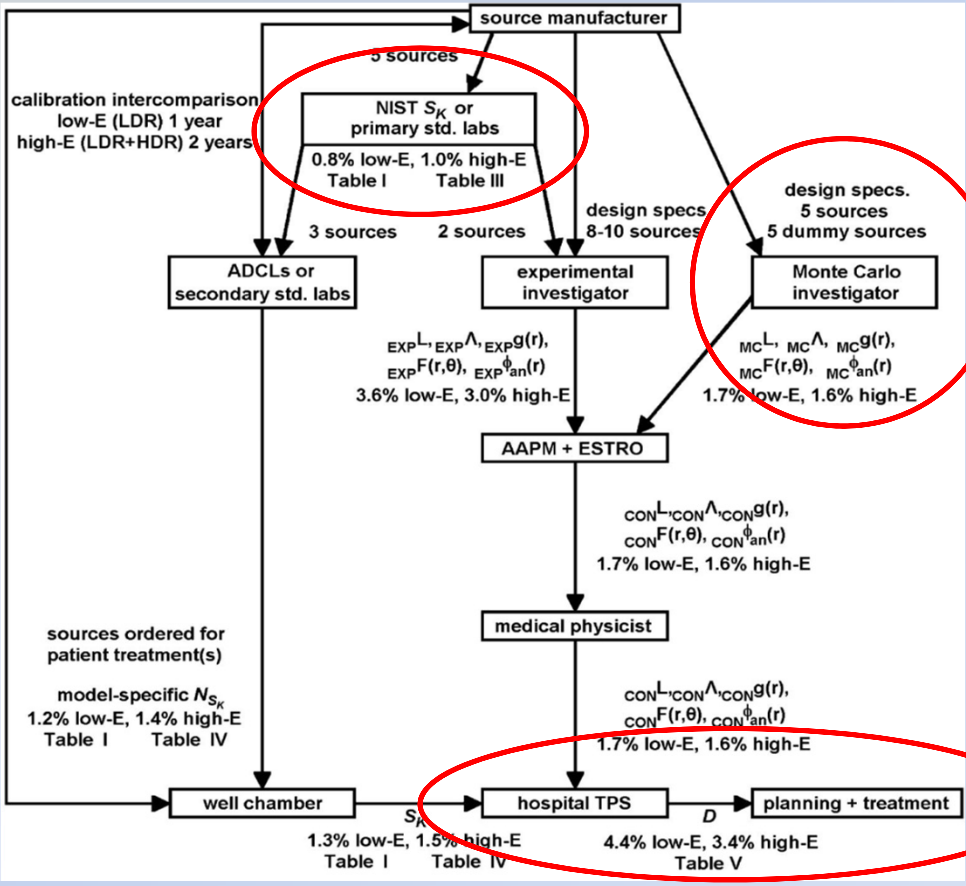
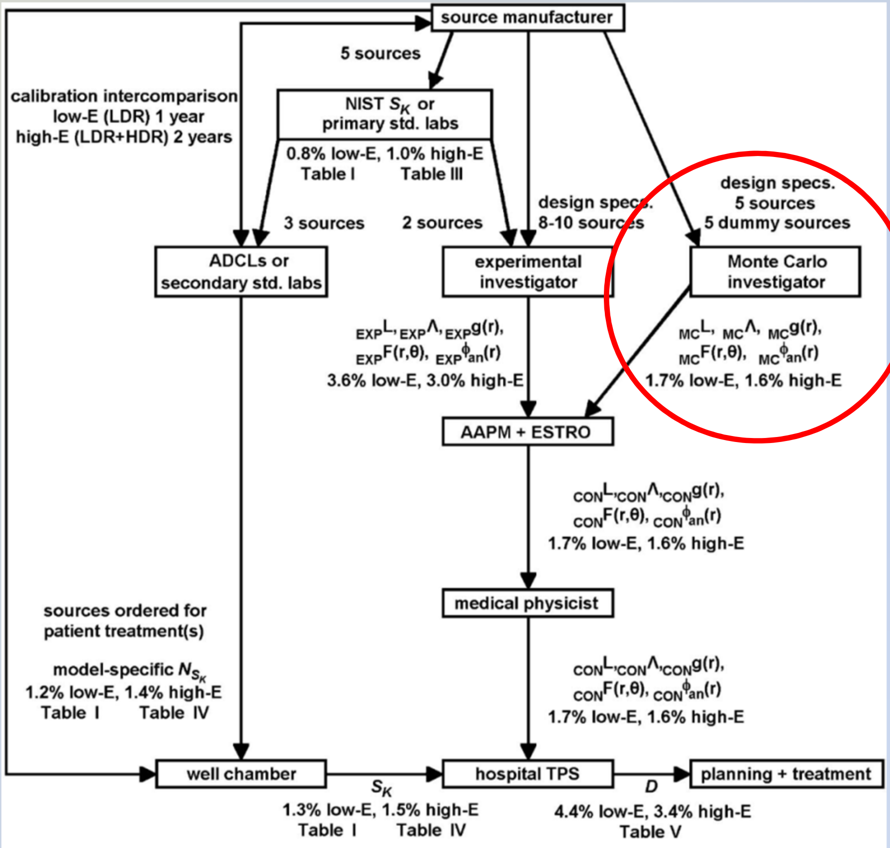
Dosimetry for treatment planning of LDR prostate brachytherapy relies on:

- air kerma strength calibration of sources, S_K (traceable to a primary standard)
- a Monte Carlo generated, relative dose rate matrix (per unit S_K) (independently verified experimentally)



DeWerd et al. Med. Phys. 38 (2011)

Accounting for MC type B uncertainties arising from uncertainty of the seed geometry is recommended in the updates of TG43 as well as AAPM/ESTRO TG-138



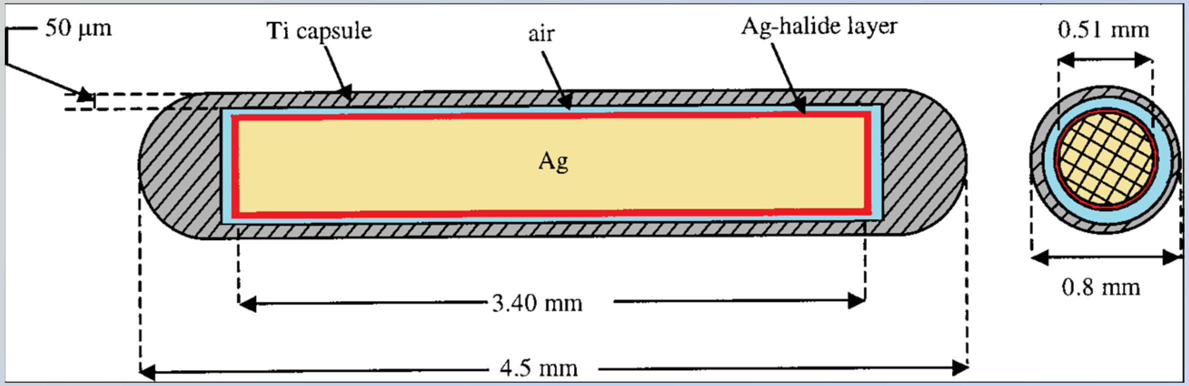
MC type B uncertainties:

1. **<u>Source Construction</u>**
2. Movable components
3. Source emissions
4. Phantom geometry
5. Phantom composition
6. Radiation transport code
7. Interaction and scoring cross sections
8. Scoring algorithms and uncertainties

DeWerd et al. Med. Phys. 38 (2011):

“A sophisticated MC dosimetric analysis would simulate the influence of varying each of these components and estimate the resultant effect of these uncertainties on the calculated dose distribution.”

The manufacturer stated tolerance of 5 construction parameters were considered for a commercially available seed



Parameter	Nominal value, x_i (mm)	Uncertainty, u_{xi} (mm)*
Radioactive Silver-Halide layer thickness	0.003	0.001
Cylindrical Silver rod length	3.4	0.05
Cylindrical Silver rod diameter	0.51	0.02
Titanium tube length	4.5	0.01
Titanium tube diameter / weld diameter	0.8	0.05

*calculated assuming normal distribution of parameters within tolerance

Materials and methods

- Let $f = \dot{D}/S_k$ the 2D relative dose rate distribution on a plane including the source long axis.

- Using MCNP5 v.1.40, 2 MC runs (water and air) were performed for the set of nominal values of source construction parameters x_i to obtain f_{nom}.

- Assuming f is approximately linear and no x_i correlation exists, the total geometric uncertainty, u_{geo} , can be calculated according to the law of uncertainty propagation:

$$u_{\dot{D}/S_k}^{\;2} = \sum_{i=1}^{5} \left(\frac{\partial f}{\partial x_i}\right)^2 u_{x_i}^{\;2} \qquad (1)$$

- The partial derivatives were approximated by the forward and backward finite differences.

Each x_i was individually changed to x_i+u_{xi} or x_i-u_{xi} and MC runs were performed to obtain $f_{+,i}$ and $f_{-,i}$ respectively.
Then:

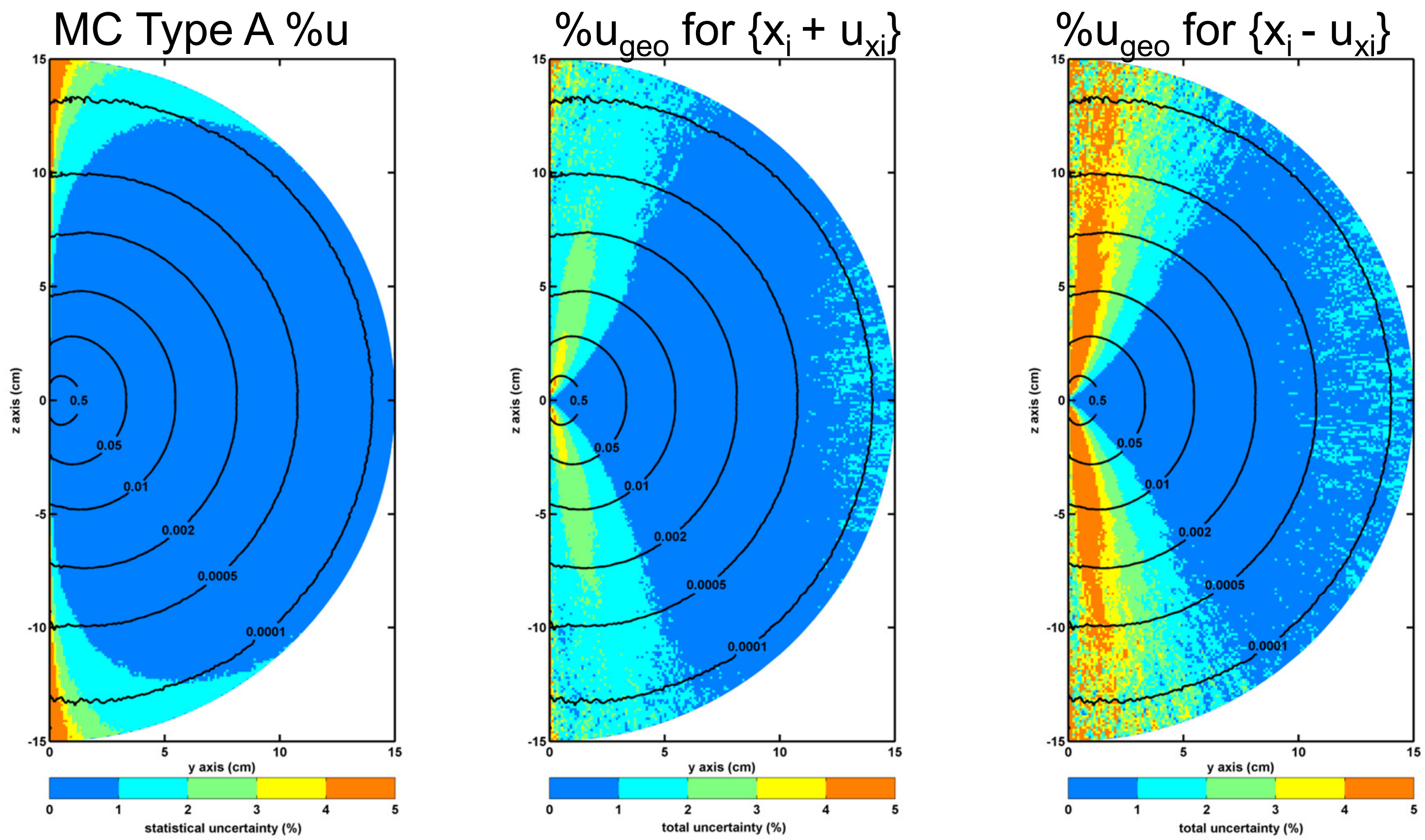
$$\frac{\partial f}{\partial x_i} \sim \frac{x_i}{f_i}\frac{\Delta f}{\Delta x_i} = \frac{x_i}{f_i}\frac{f_{+i} - f_{nom}}{u_{x_i}} \; or \; \frac{x_i}{f_i}\frac{f_{nom} - f_{-i}}{u_{x_i}} \qquad (2)$$

Single source results Sk

Parameter, x_i	$S_{K\ nom}$ (U) $\cdot 10^{-4}$	$S_{K\ +,i}$ (U)$\cdot 10^{-4}$	$S_{K\ -,i}$ (U) $\cdot 10^{-4}$
Radioactive Silver-Halide layer thickness	2.4276	2.4210	2.4346
Cylindrical Silver rod length		2.4292	2.4259
Cylindrical Silver rod diameter		2.4086	2.4453
Titanium tube length		2.4275	2.4275
Titanium tube diameter / weld diameter		2.0230	2.9446

- S_K exhibits a 38 % variation due to construction tolerance
- this underlines the importance of source S_K calibration
- we are concerned with the uncertainty of $f = \dot{D}/S_k$ in the MC data set in the clinical TPS

Single source results



• Radioactive coating thickness, end weld radius major uncertainty contributors

• uncertainties position dependant

• 0.2% compared to DeWerd et al. @ (1, 90)

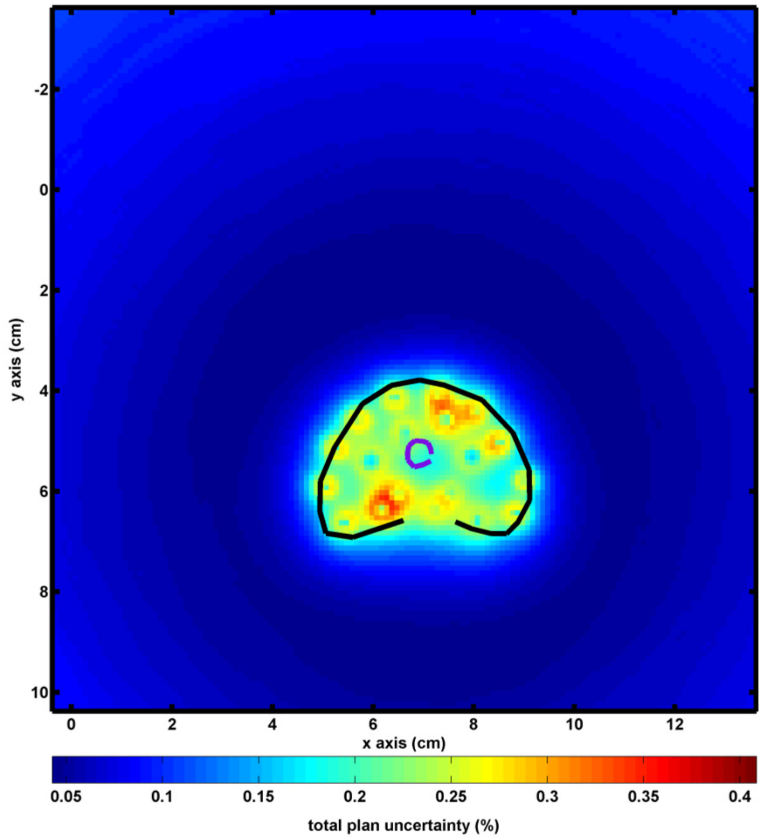
• $\%u_{geo}$ for $\{x_i - u_{xi}\}$ was adopted as a worst case scenario

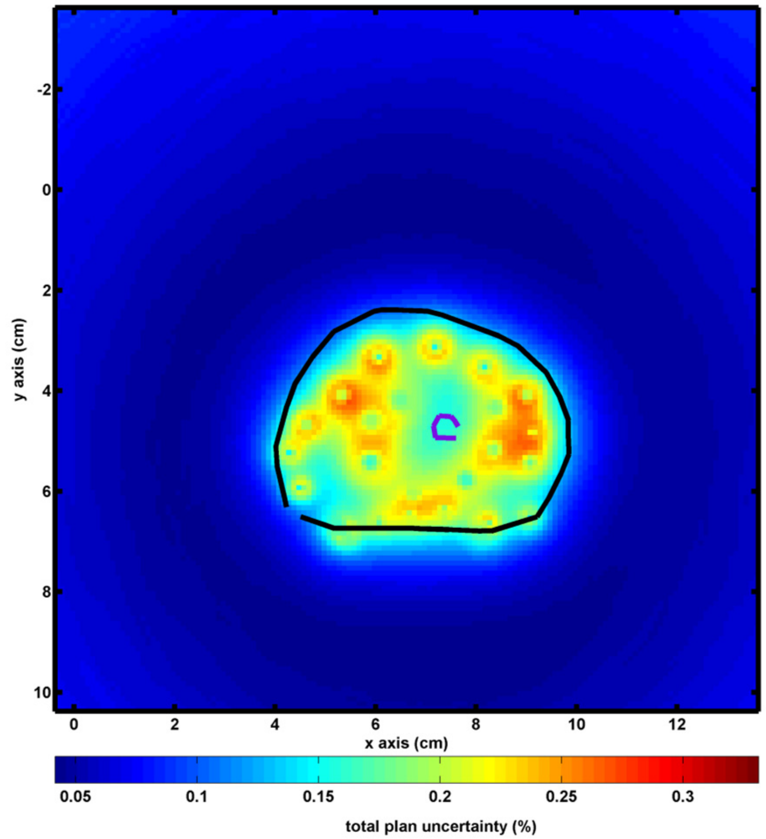
Results in clinical LDR prostate brachytherapy plans

Patient plans were exported in dicom-RT.
The superposition principle was used to generate the 3D dose distribution.
u_{geo} from the implanted sources was combined in quadrature at each point of the 3D dose distribution.

Small / 65 dwell positions (default)

Large / 89 dwell positions

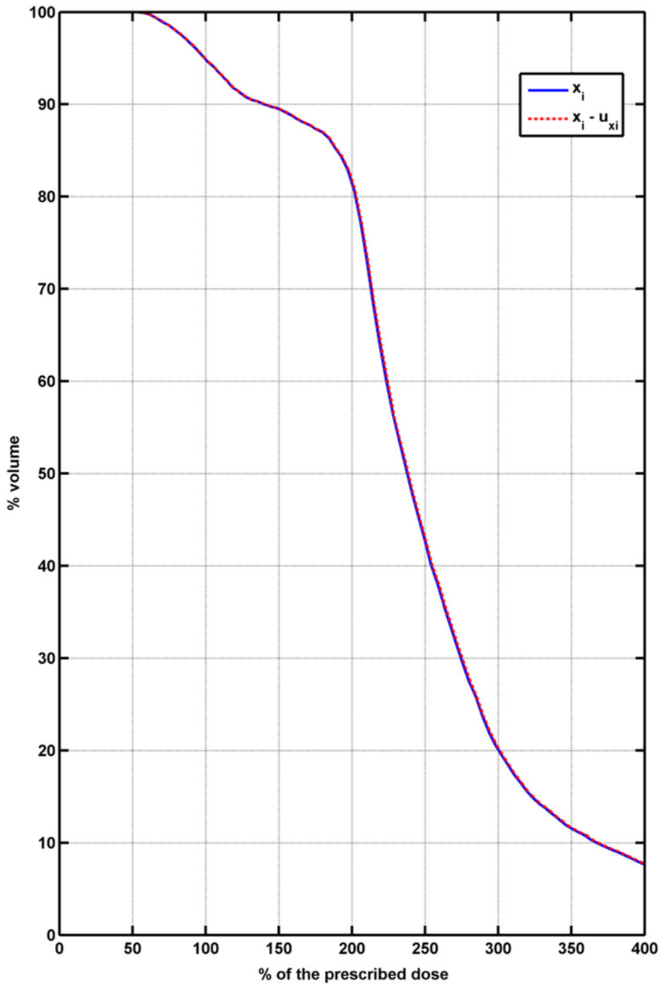




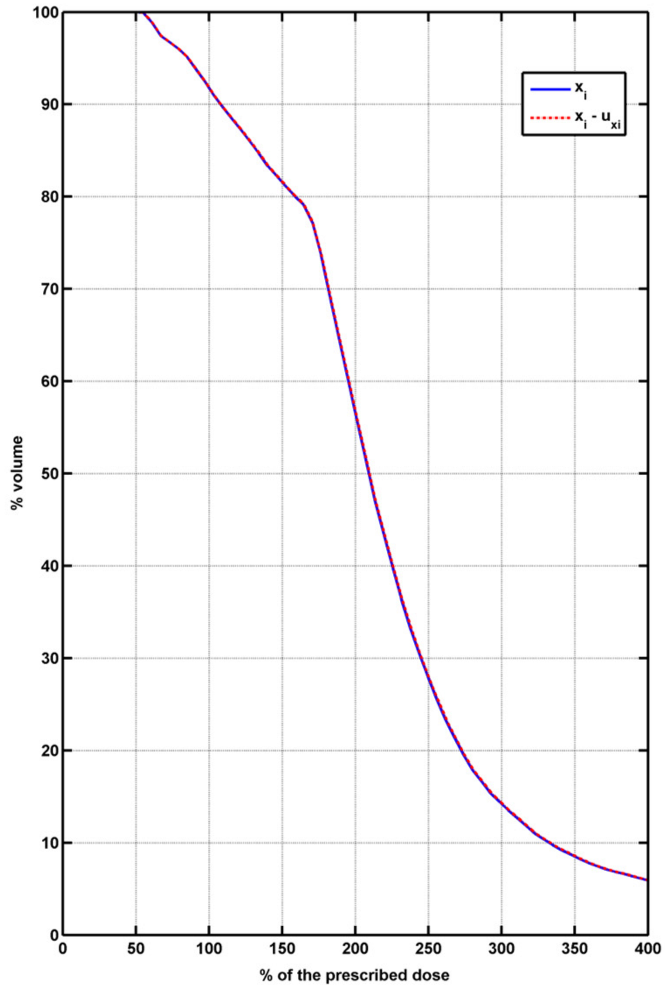
Results in clinical LDR prostate brachytherapy plans

DVH differences < 0.1% on D_{90}

Small / 65 dwell positions (default)



Large / 89 dwell positions



Discussion

- **Specific source model** ^{125}I LDR brachytherapy applications

- Total MC uncertainties typeA + type B (statistics, photoionization, cross sections, source energy spectrum, **seed geometry**,…) of about 1.7%[1] to 2.5%[2]

- Clinical dosimetric uncertainties (inter-seed attenuation 2%-5% reduction of D_{90},[3] heterogeneities 3%, 4% on D_{90},[3] seed localization uncertainty <5%,[4] anatomy changes between dose delivery and post-implant imaging 5%,[5] …) ~ 11%

1. DeWerd et al. Med. Phys. 38 (2011)
2. Rivard et al. Med. Phys. 31 (2004)
3. Carrier et al. Int. J. Radiat. Oncol. Biol. Phys. 68 (2007)
4. Su et al. Phys. Med. Biol. 52 (2007)
5. Yue et al. Med.Phys. 26 (1999)

Conclusions

• Although source construction uncertainties are not the major source of single source dosimetric uncertainties, sometimes manufactured sources may differ from their design, so MC simulations is recommended to be performed with representations of the final clinically delivered product.

• While uncertainties as a topic have been receiving much more attention over the years and the quantification of source construction effects suffers from the lack of a routine clinical method to obtain source specific average data, this work proposed a method for each dosimetry investigator to estimate the overall dosimetric uncertainties related to a specific source model and clinical protocol being studied.

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Thank you!!!

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