# *Systematic error in MCNP's pebbles modelling*

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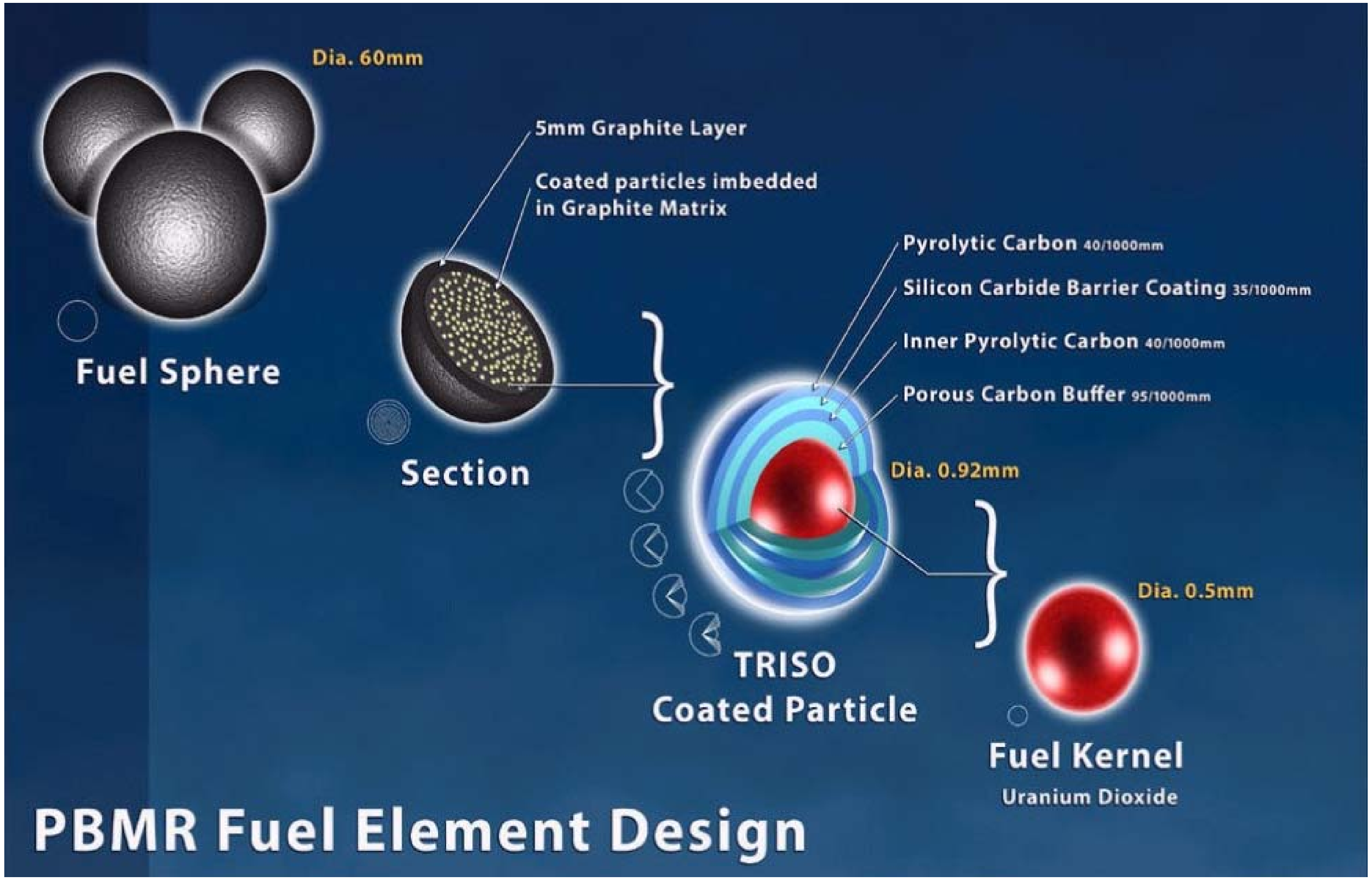
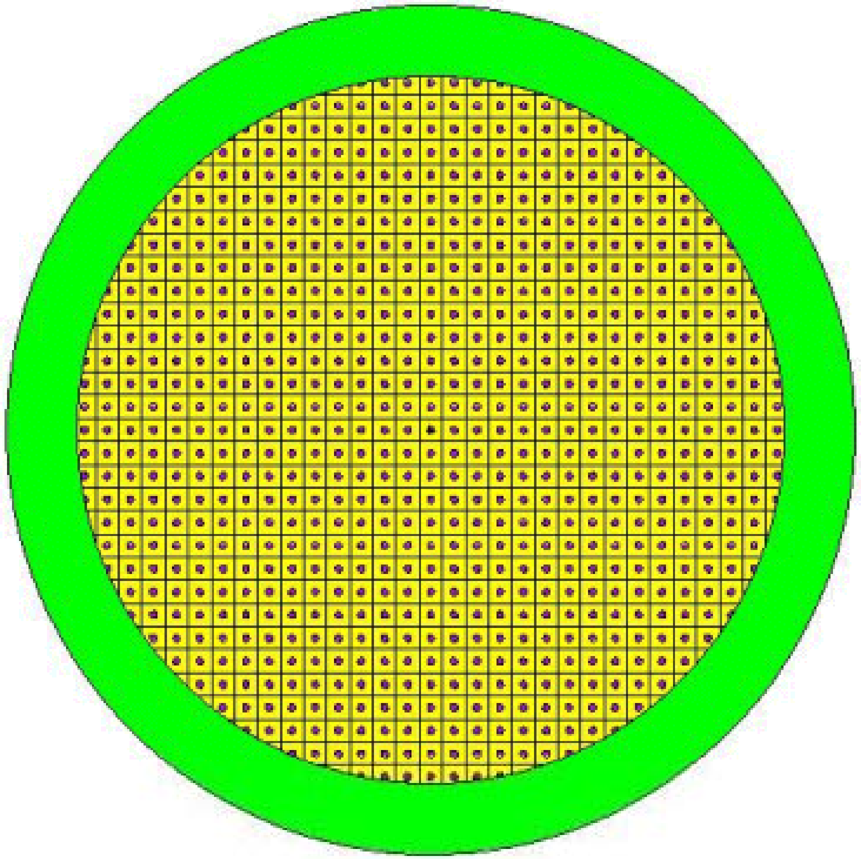
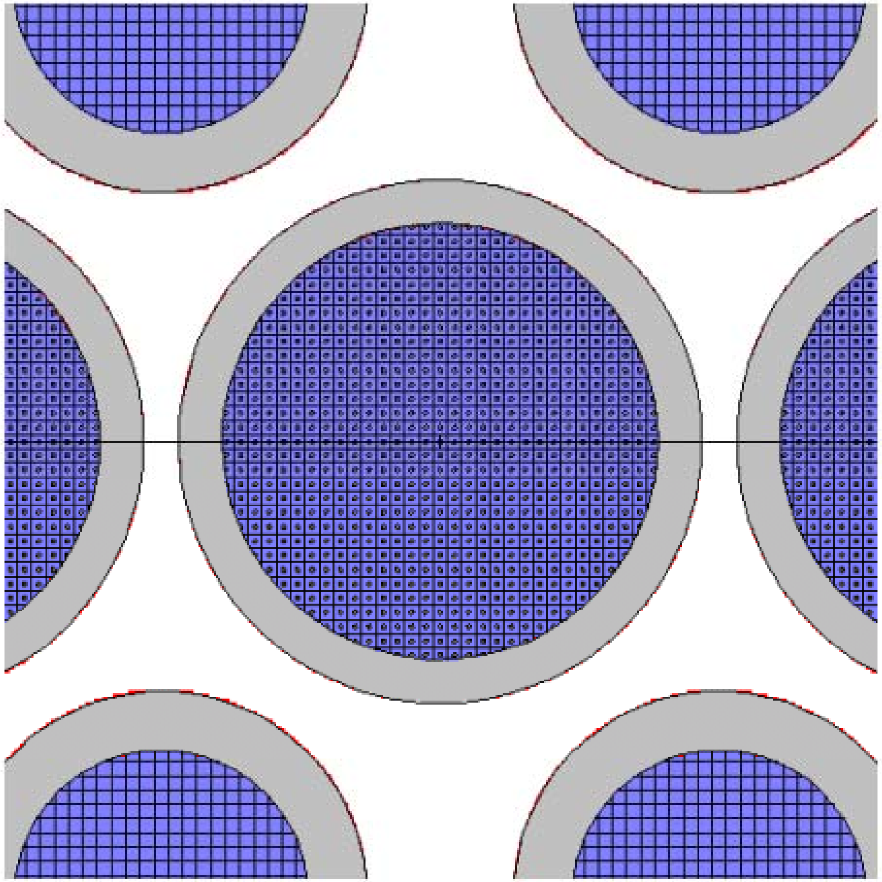

Dia. 60mm
Fuel Sphere
5mm Graphite Layer
Coated particles imbedded
in Graphite Matrix
Section
Pyrolytic Carbon 40/1000mm
Silicon Carbide Barrier Coating 35/1000mm
Inner Pyrolytic Carbon 40/1000mm
Porous Carbon Buffer 95/1000mm
Dia. 0.92mm
TRISO
Coated Particle
Dia. 0.5mm
Fuel Kernel
Uranium Dioxide
PBMR Fuel Element Design





$$N_K = \sum_{i=-M}^{M} \sum_{j=-M}^{M} \sum_{k=-M}^{M} f_{ijk}$$

with

$$M = \left\lfloor \frac{R_P}{P} \right\rfloor$$

$$f_{ijk} = \begin{cases} 1 & R_{ijk} < R_P \\ 0 & Otherwise \end{cases}$$

with

$$R_{ijk} = P\sqrt{i^2 + j^2 + k^2}$$

where

$N_K$ is the number of kernels inside the pebble,

$R_P$ the radius of the pebble matrix,

$P$ the pitch of the cubic lattice,

and the brackets represents the largest integer number lower than the argument (“integer part”).

| Number of kernels (design parameter) | Number of points of the cubic lattice inside the pebble | Number of effective kernels inside the pebble |
|---|---|---|
| 10000 | 10395 | 9969.3 |
| 11000 | 11363 | 11003.0 |
| 12000 | 12293 | 11975.9 |
| 13000 | 13397 | 13054.1 |
| 14000 | 14411 | 13966.1 |
| 15000 | 15515 | 15040.0 |
| 16000 | 16519 | 15980.9 |
| 17000 | 17461 | 16997.0 |
| 18000 | 18613 | 17975.6 |
| 19000 | 19549 | 19049.1 |
| 20000 | 20479 | 19985.1 |

**Table 1: geometric and mass effects on the numbers of kernels for a pebble matrix of 2.5 cm radius and kernels of 0.025 cm radius.**

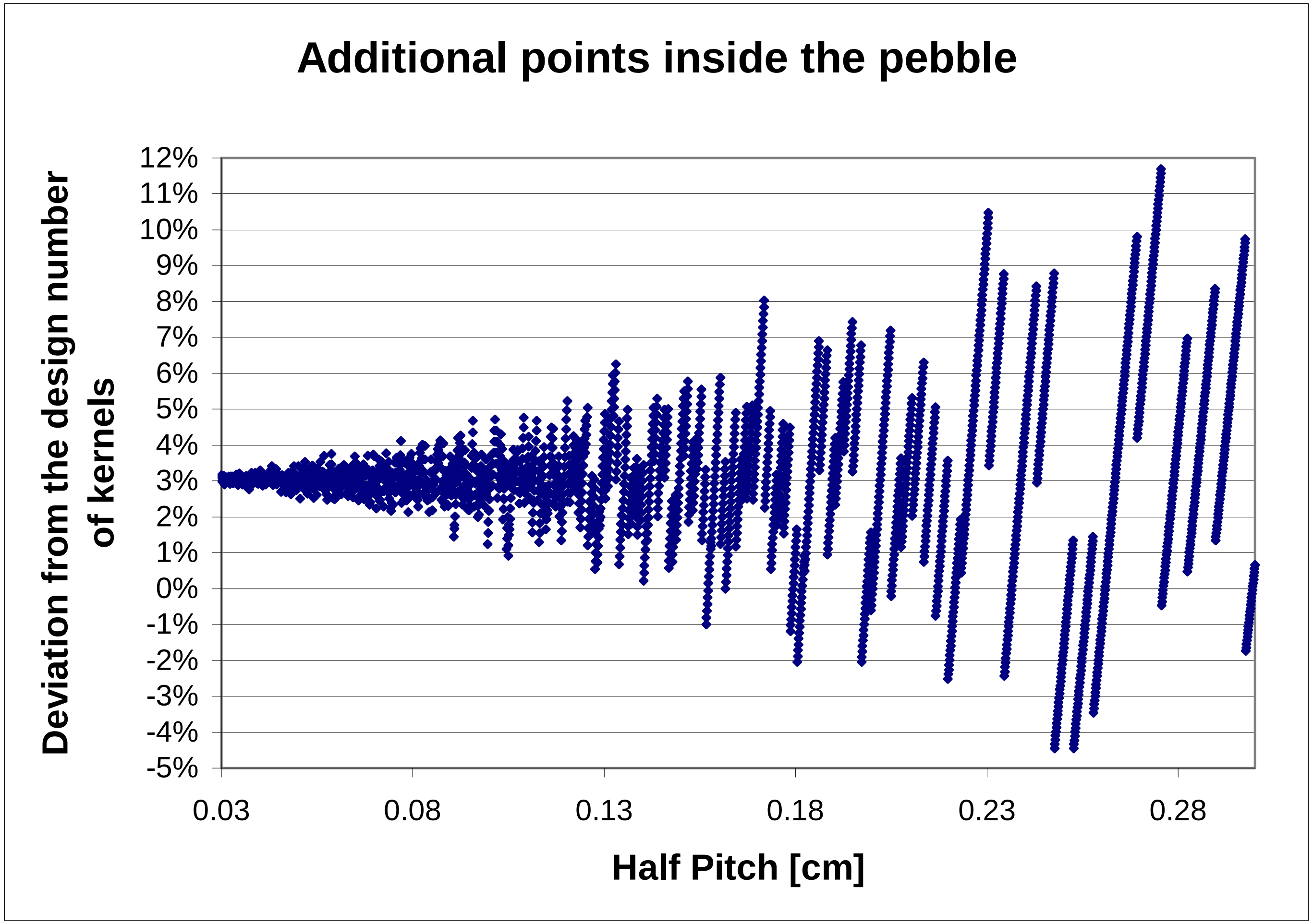



**Figure 1: Additional points inside the pebble as a fraction of the design numbers of kernels (for a pebble matrix of 2.5 cm radius and kernels of 0.025 cm radius).**

- In the range of PBMR pebbles design the error in the number of points is between 2% and 4%.
- There exist “magical” pitches where the error is 0%.
- Negative (or 0%) errors can be achieved for pitches/2 greater than 0.14 cm (~d/36).

$$V_T = \sum_{i=-M}^{M} \sum_{j=-M}^{M} \sum_{k=-M}^{M} V_{ijk} \qquad \text{with} \qquad M = \left\lfloor \frac{R_P + R_K}{P} \right\rfloor$$

$$V_{ijk} = \begin{cases} \frac{4}{3}\pi R_K^3 & R_{ijk} + R_K \le R_P \\ 0 & R_{ijk} + R_K \ge R_P \\ \frac{\pi}{24 R_{ijk}^3} \left\{ \begin{array}{l} \left[R_K^2 - \left(R_{ijk} - R_P\right)^2\right]^2 \left[6 R_{ijk} R_P + \left(R_{ijk} - R_P\right)^2 - R_K^2\right] + \\ + \left[R_P^2 - \left(R_{ijk} - R_K\right)^2\right]^2 \left[6 R_{ijk} R_K + \left(R_{ijk} - R_K\right)^2 - R_P^2\right] \end{array} \right\} & R_P - R_K < R_{ijk} < R_P + R_K \end{cases}$$

with $$R_{ijk} = P\sqrt{i^2 + j^2 + k^2}$$

where

$V_T$ is the total volume of kernels inside the model of the pebble,

$R_K$ is the radius of a kernel, and the rest of the parameters were already defined.

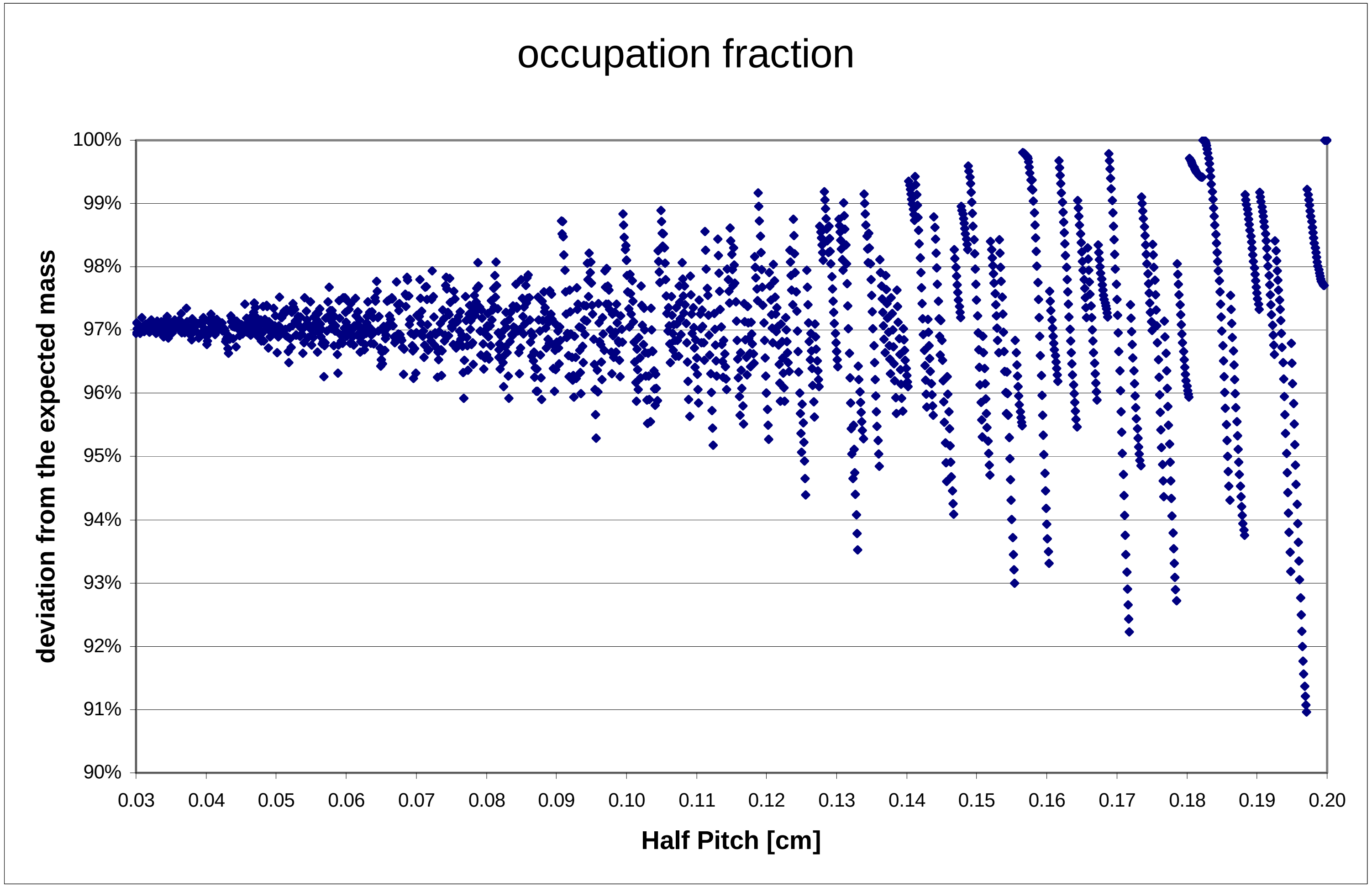



**Figure 2: fraction of the expected mass of kernels introduced in the model of a pebble (for a pebble matrix of 2.5 cm radius and kernels of 0.025 cm radius).**

- In the range of PBMR pebbles design the error in the mass introduced in the model (with respect to the expected value) is between -2% and -4%.
- There exist “magical” pitches where the error is 0%.

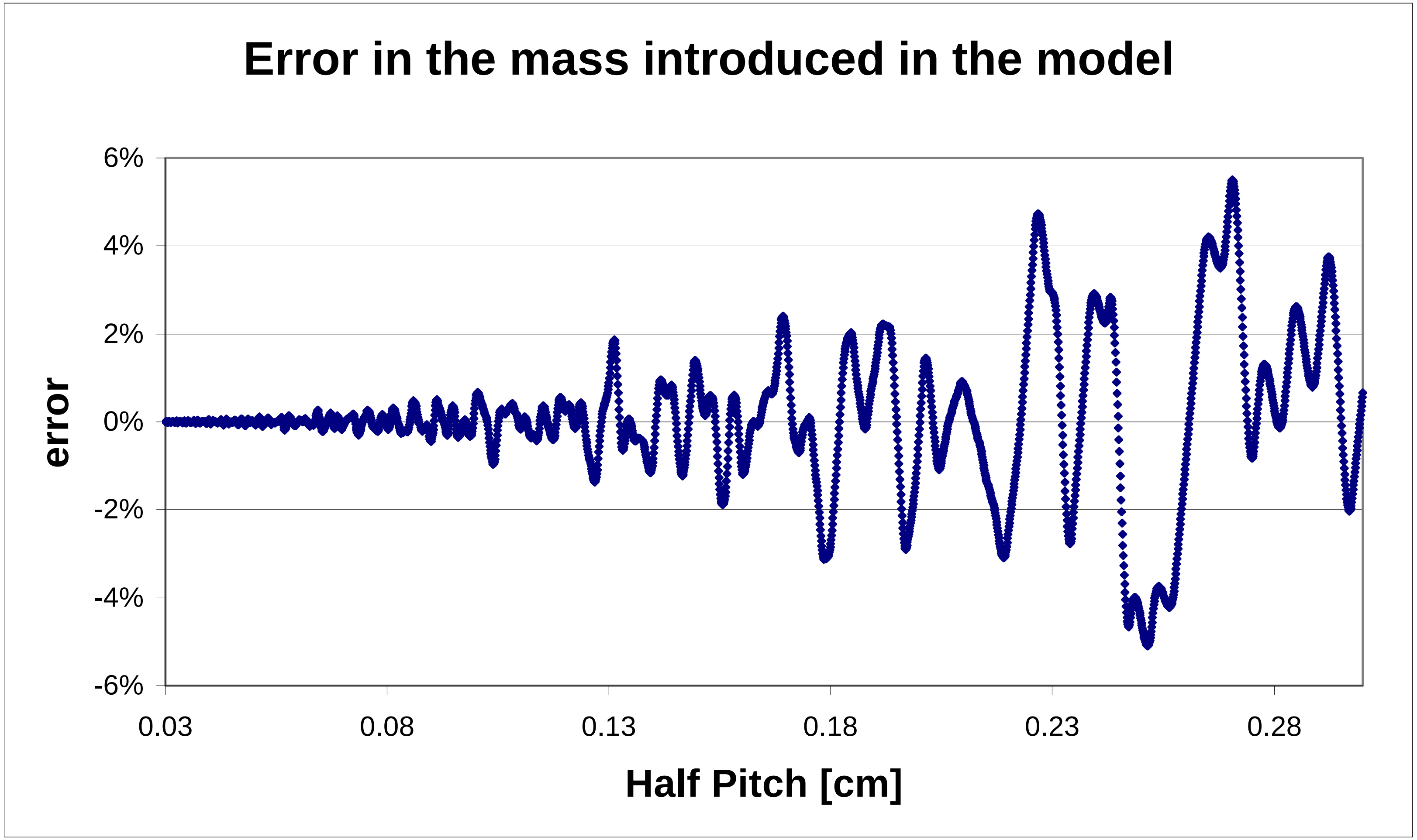



**Figure 3: error in the mass of uranium introduced in the model of a pebble (for a pebble matrix of 2.5 cm radius and kernels of 0.025 cm radius).**

It is remarkable:

- the cancellation effect.
- the continuum behaviour of the error as a function of the pitch.
- the high number of “magical pitches” where the error introduced in the model is null, even for relative big pitches.

The most relevant issue is that
for today’s pebble design
($R_P$=2.5 cm, $R_K$=250 μm, Umass=9 g, Enrich=9.6%)
the error in the mass introduced in the model is only 0.24% (negligible)
just because an ***error cancellation***,
but simple changes in the design parameters
(bigger kernels, less uranium mass, bigger pebbles, more enrichment)
would lead to errors in the MCNP model of 3% or more.

# Conclusion

- Be paranoid,
- and check everything twice.