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The stochastic finite element method and its possible use in thermo-mechanical drift calculations

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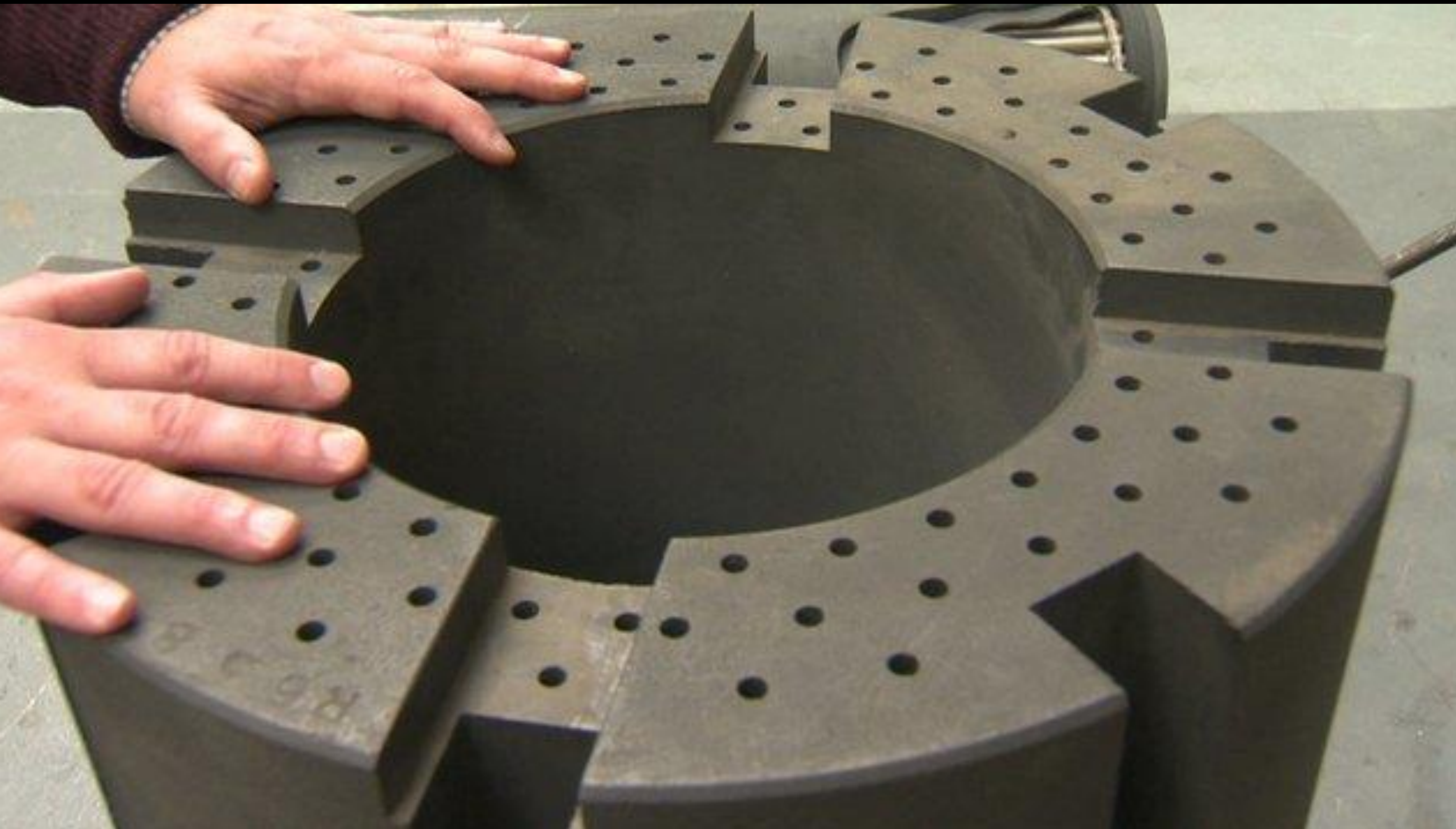
Overview

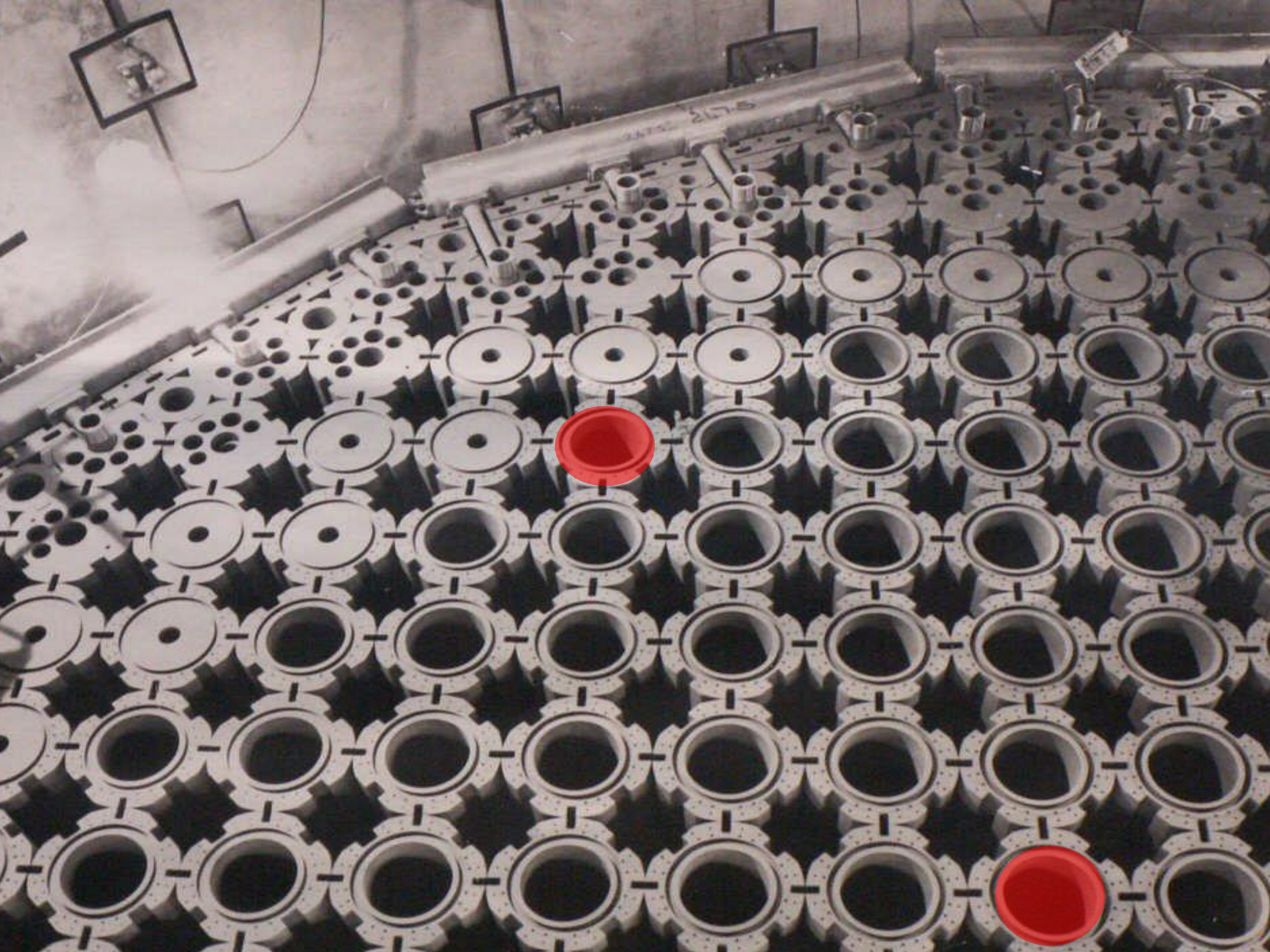
- Context – safety in nuclear reactors
- Reactor core inspection
- Classical predictive FE modelling
- Overview of stochastic FE modelling
- Results for nuclear graphite bricks
- Applicability to thermo-mechanical drift

Cracks found at reactor at Hunterston B nuclear power station

By David Miller
BBC Scotland environment correspondent

Source: http://www.bbc.com/news/uk-scotland-glasgow-west-29502329 on 6 October 2014

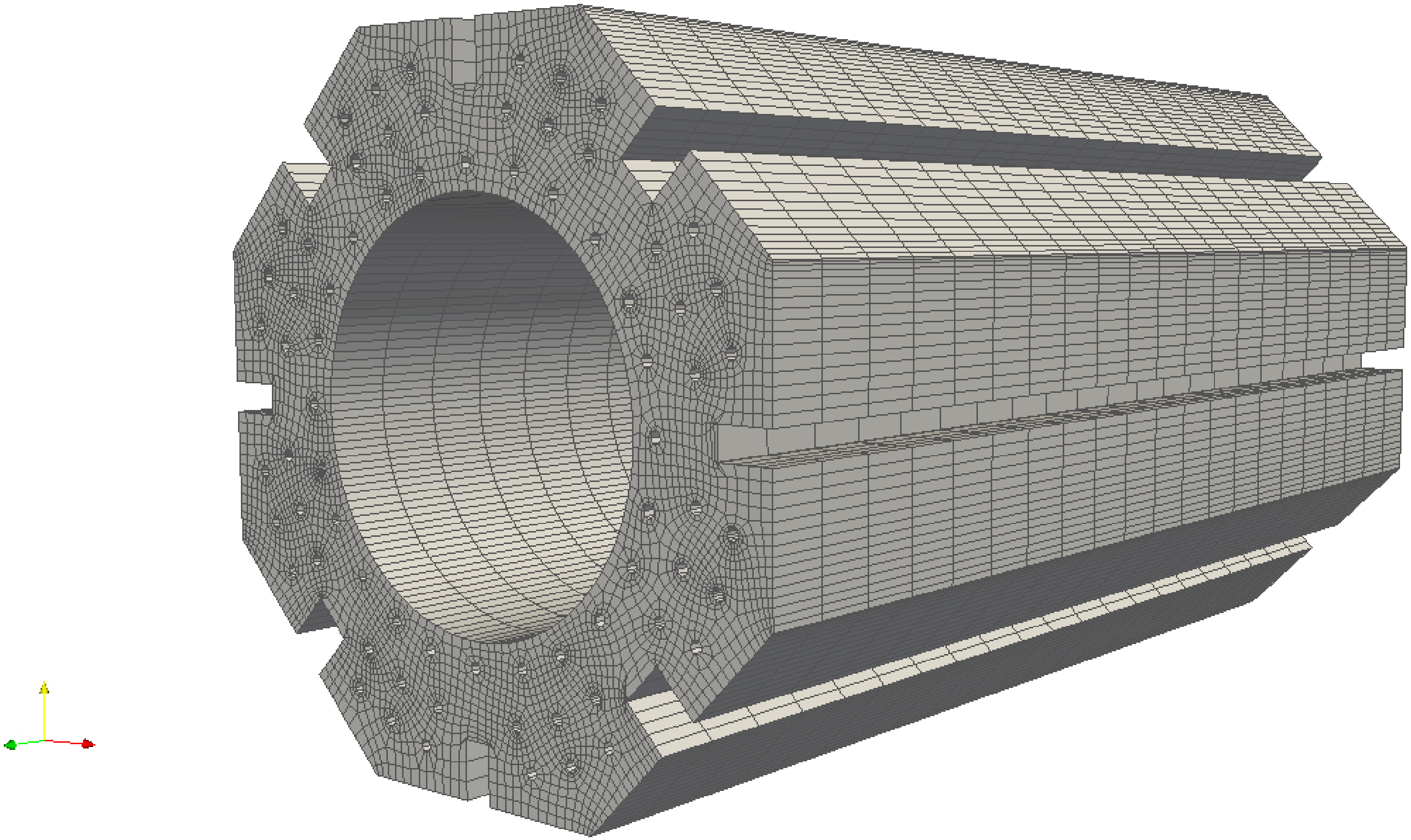




Periodic Inspection

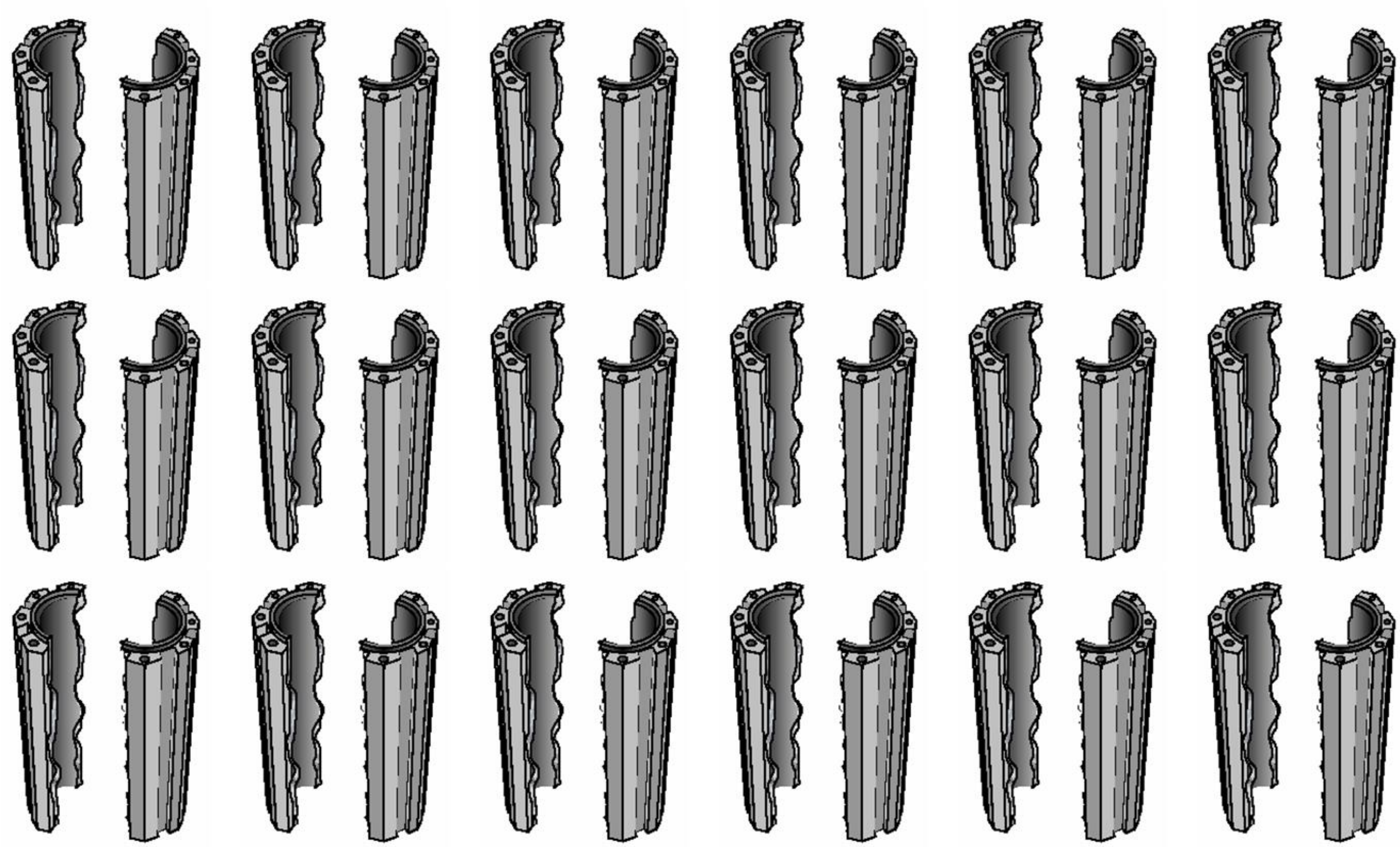
- Periodic inspections require the shut down of the reactor
- Purpose is to detect cracking
  - In the keyways, change in brick diameter
  - In the bore, change in ovality
- Some degree of cracking can be tolerated until loss of structural integrity
- Difficulty in moving fuel rods
- Safety cannot be ensured

Predictive Modeling



As simulation capability improves there are fewer shut downs for inspection and life-time predictions become more accurate.

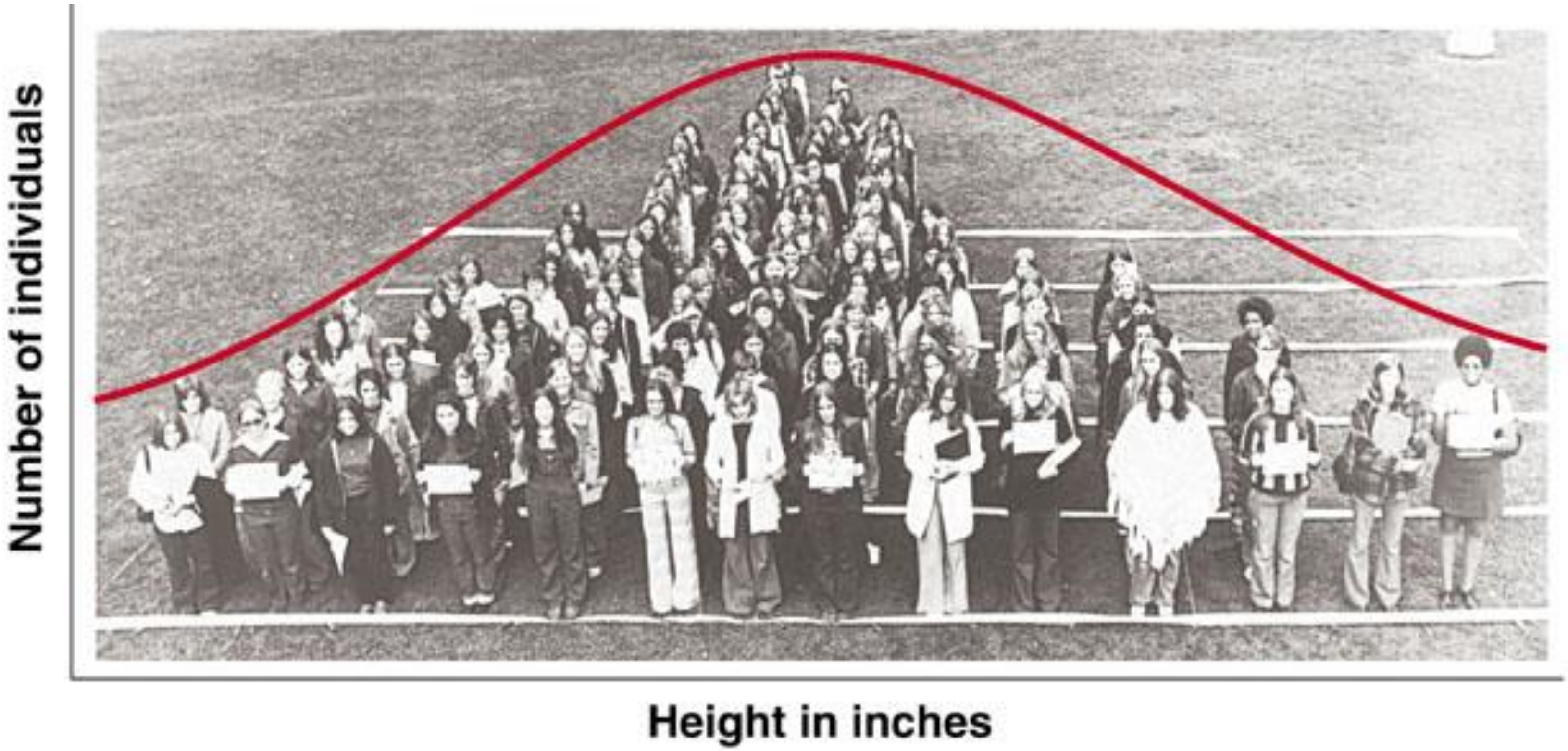
Simulated Bricks All Crack Together



But despite very complicated constitutive models, the simulations aren't quite right. And if they were correct, they would predict that all the bricks would crack at the same time, which they don't!

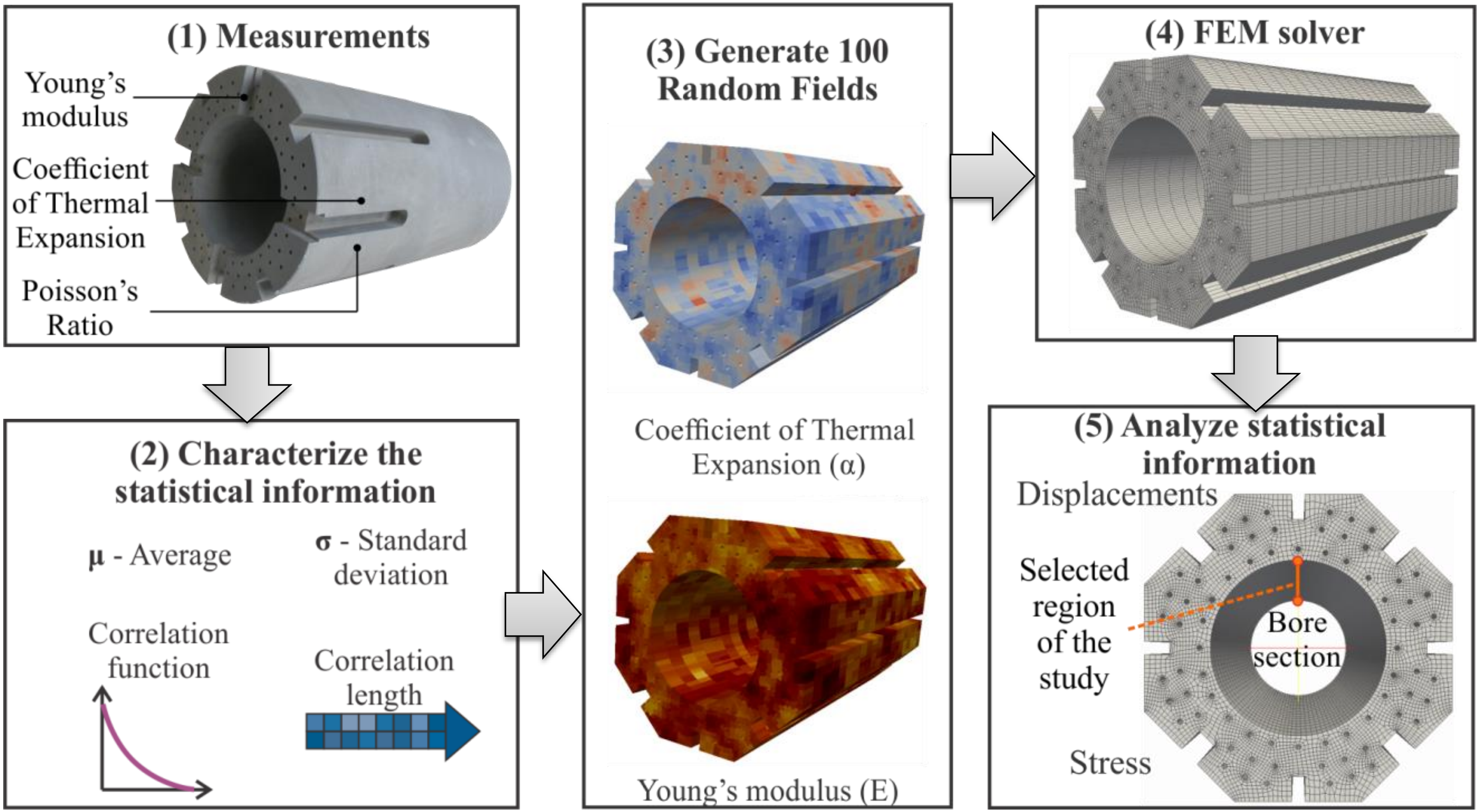
Monte Carlo Stochastic Finite Element Method

Complex Physics, but Mean E, CTE, etc



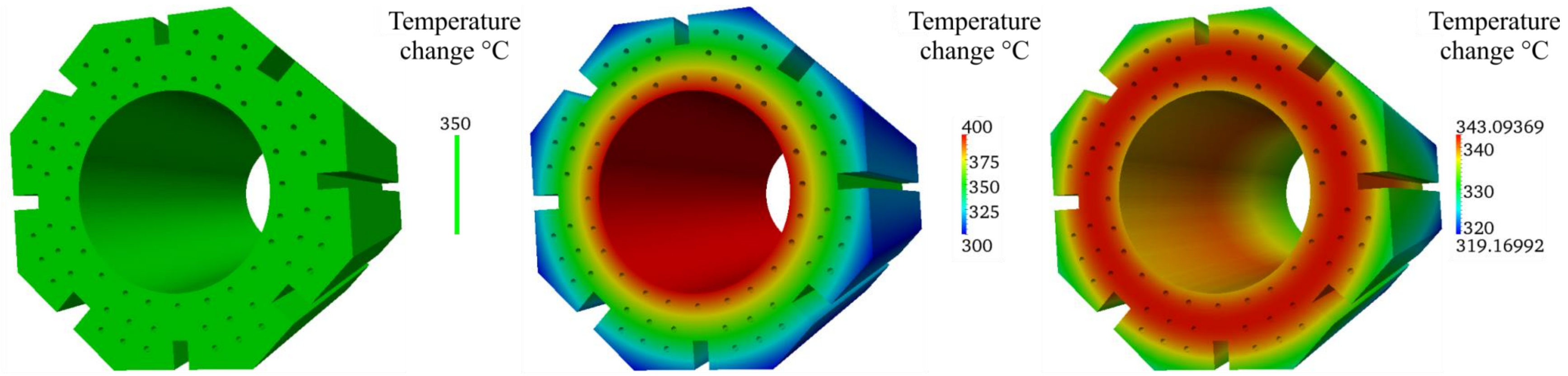
Historically, due to limitations in computer power, engineers have tended to use mean properties for finite element analysis, ignoring the standard deviation of test data. All finite elements in a component, made of steel say, will have identical stiffness, Poisson's ratio, CTE and density, to 64 bit machine precision.

Stochastic Modelling Workflow



Arregui et al. "Practical application of the stochastic finite element method", Archives of Computational Methods in Engineering, 2016

Temperature Profiles



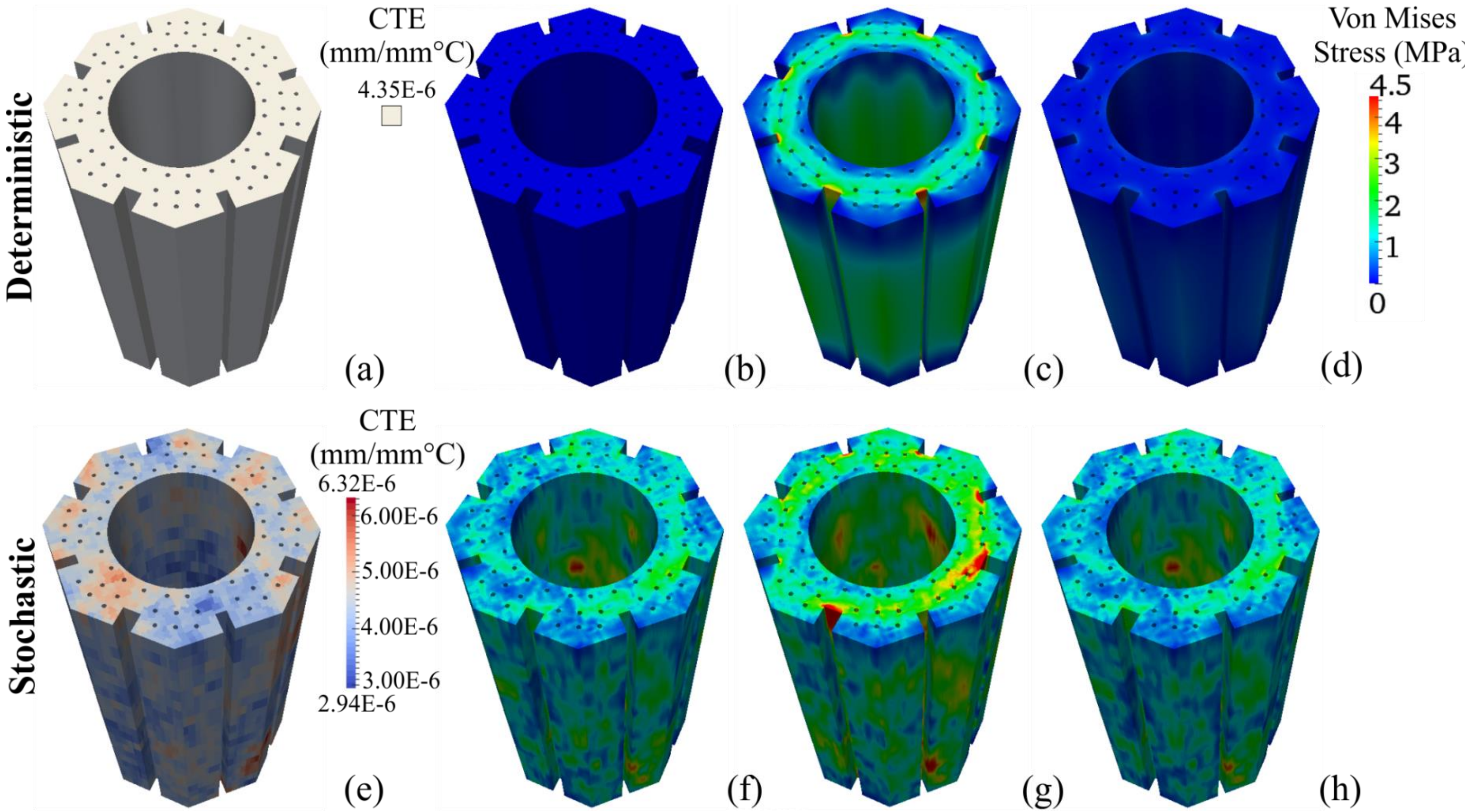
Uniform dT

Uniform
T gradient

"Real"
Temperature

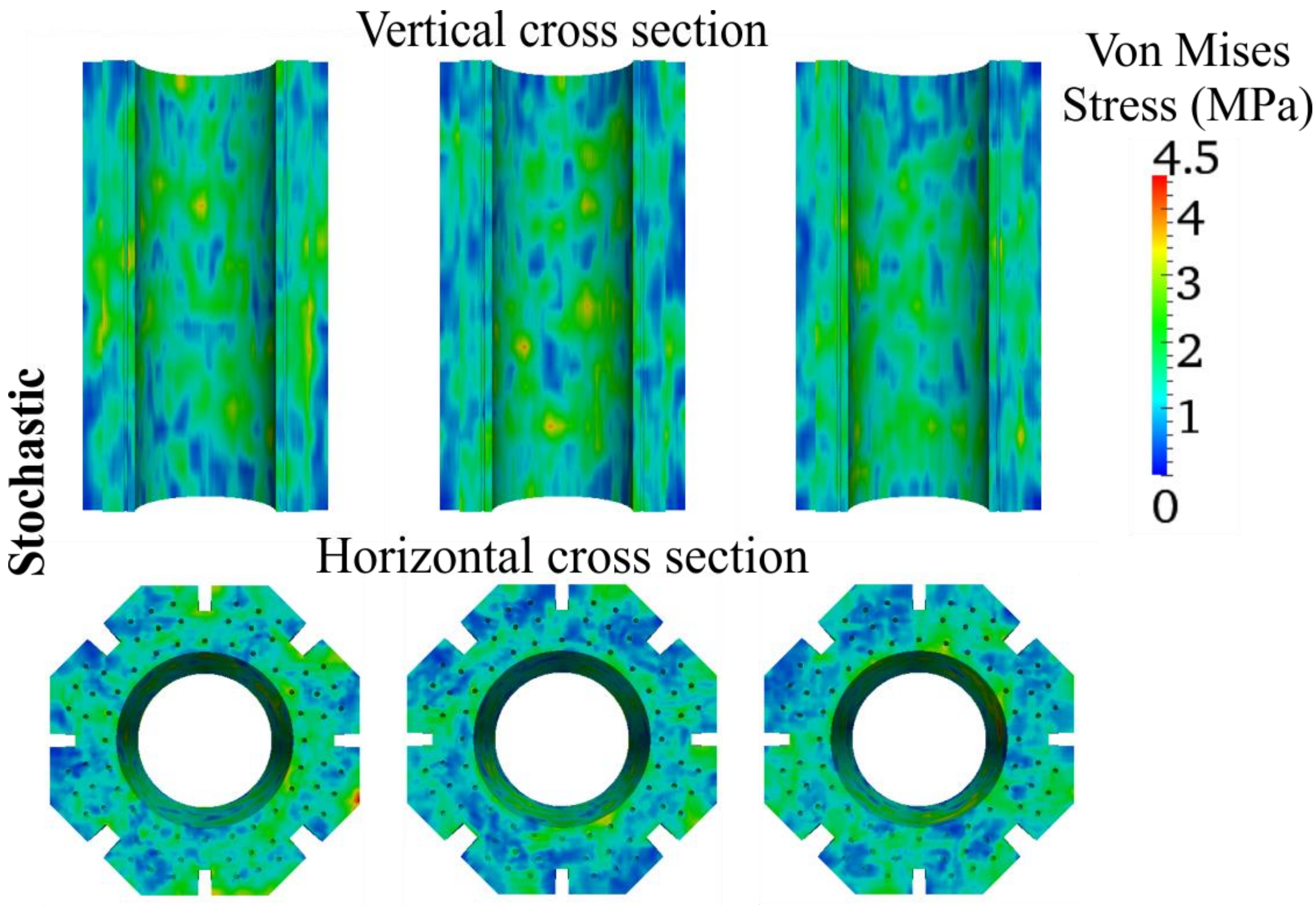
[Arregui et al. "Random spatial variability in the coefficient of thermal expansion induces pre-service stresses in computer models of virgin gilsocarbon bricks", Journal of Nuclear Materials, 2015]

Typical Stress Plots



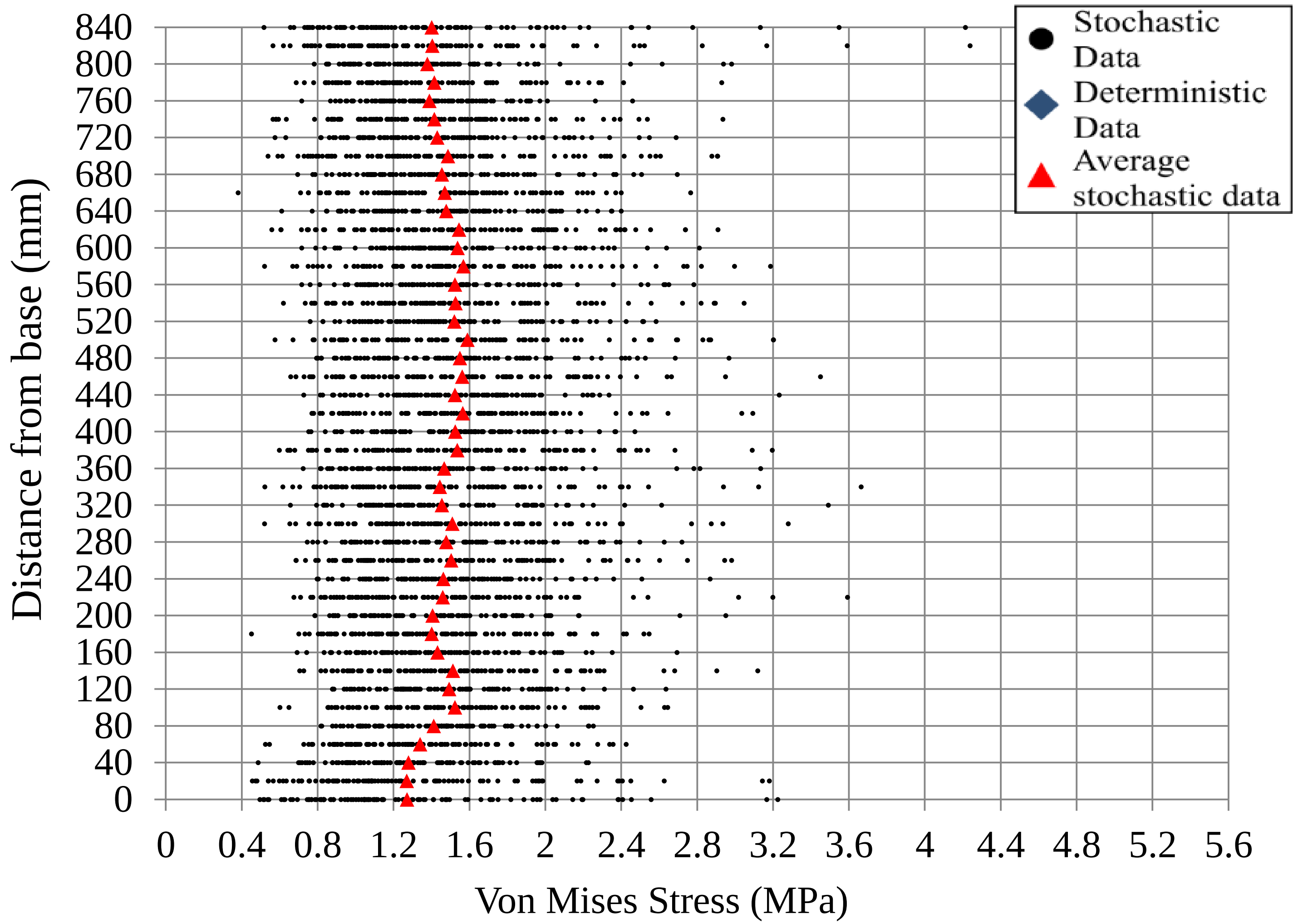
CTE | Uniform dT | Uniform T gradient | "Real" Temperature

Same Geometry, Different Properties

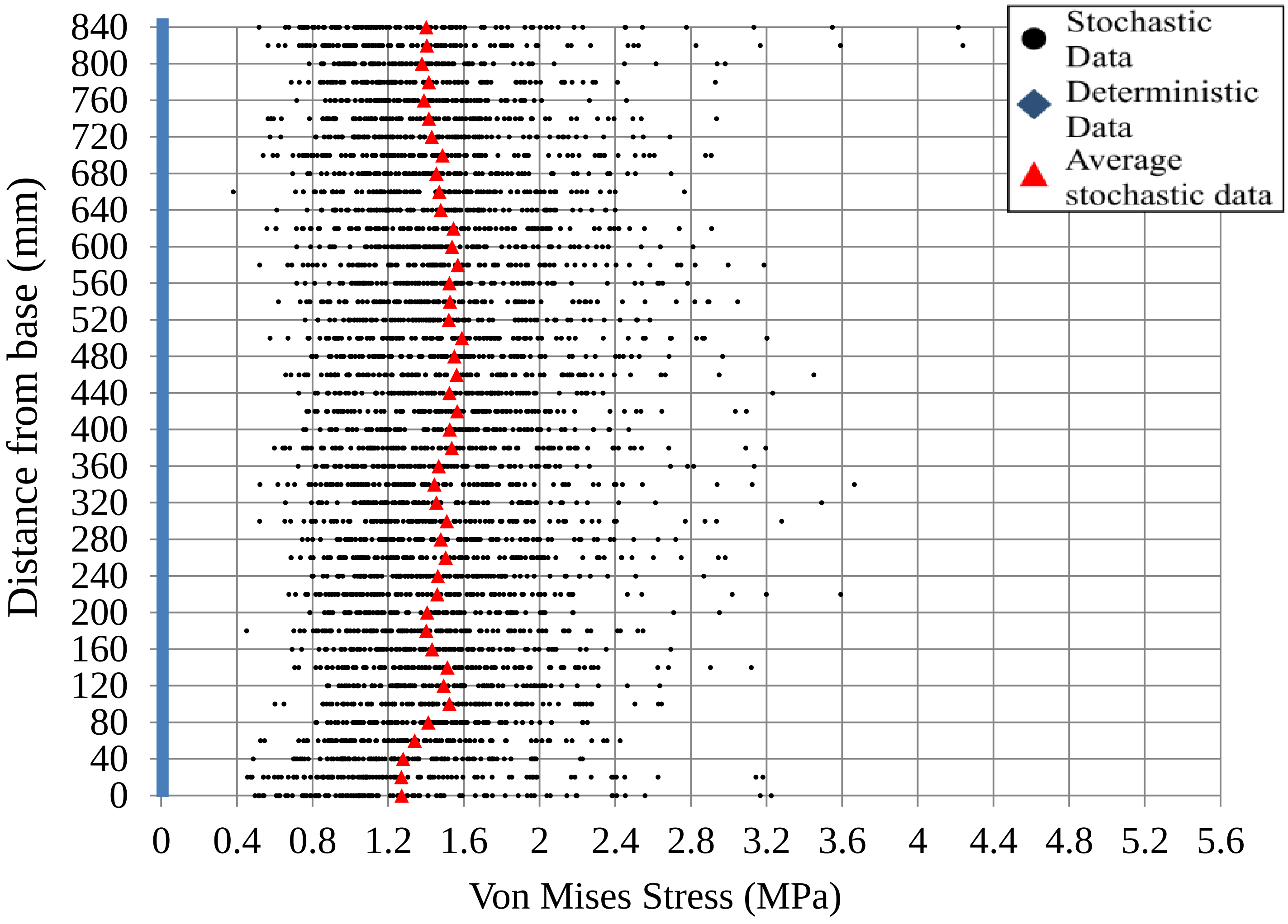


Three typical “realisations” of a Monte Carlo Finite Element Analysis.

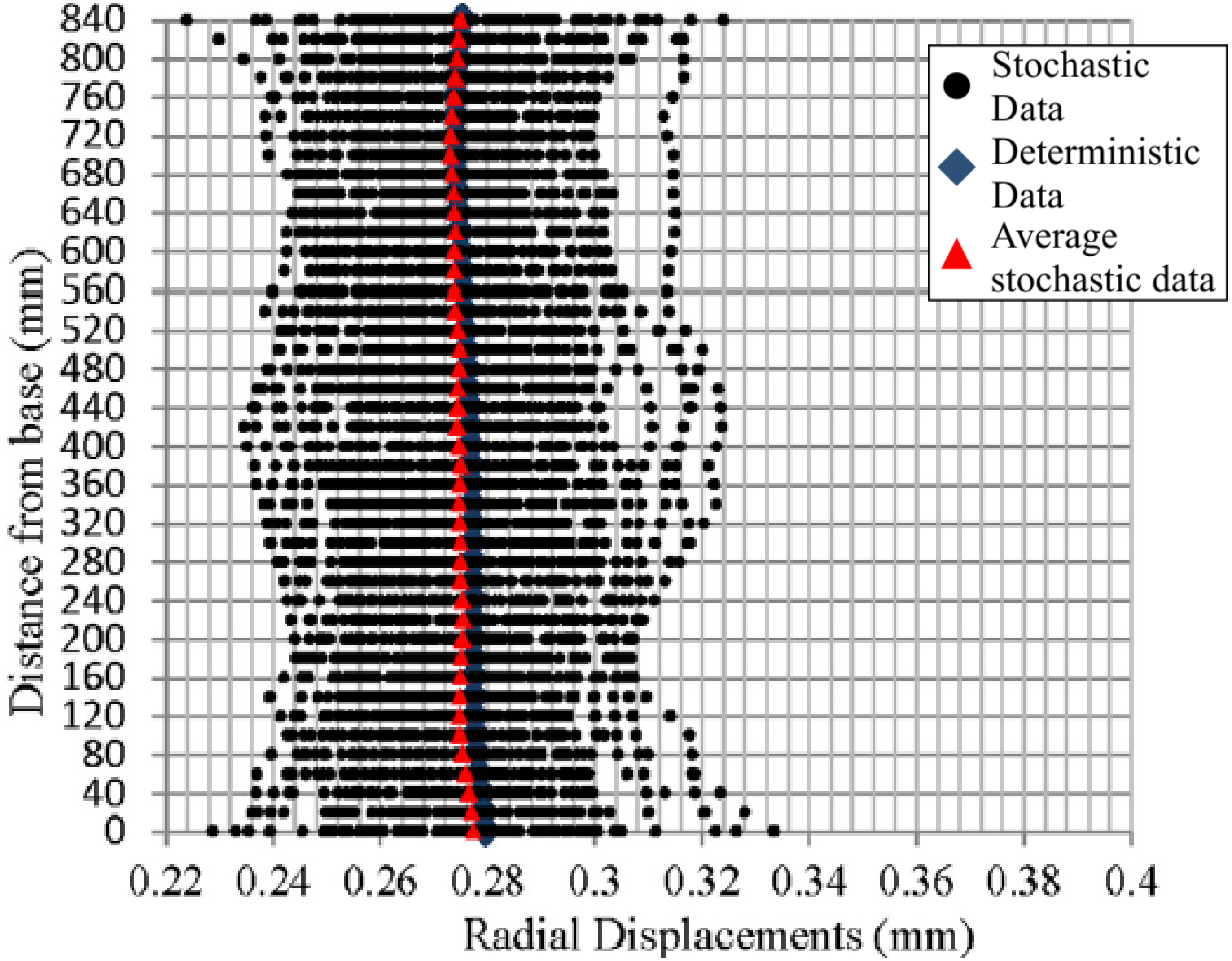
Predicted Stress With Uniform dT



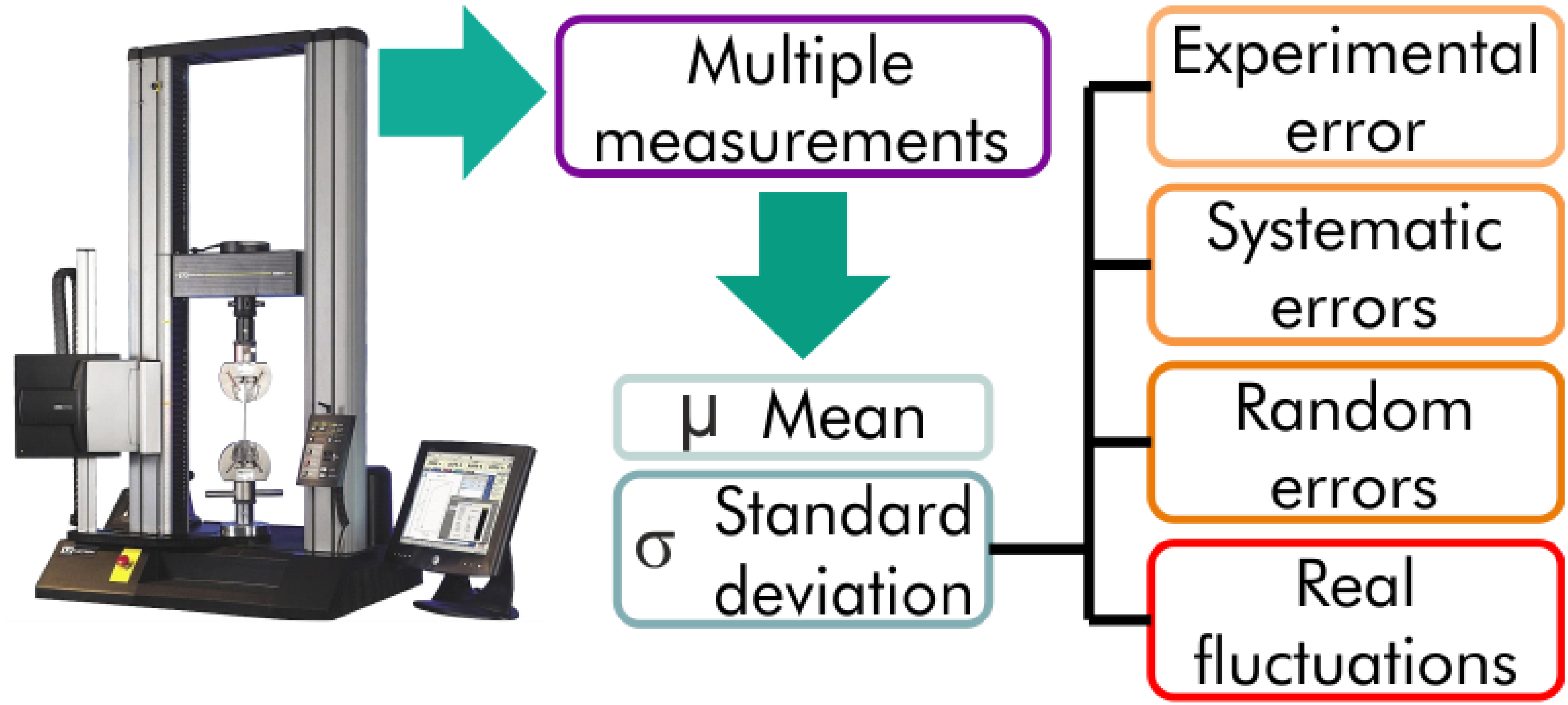
Predicted Stress With Uniform dT



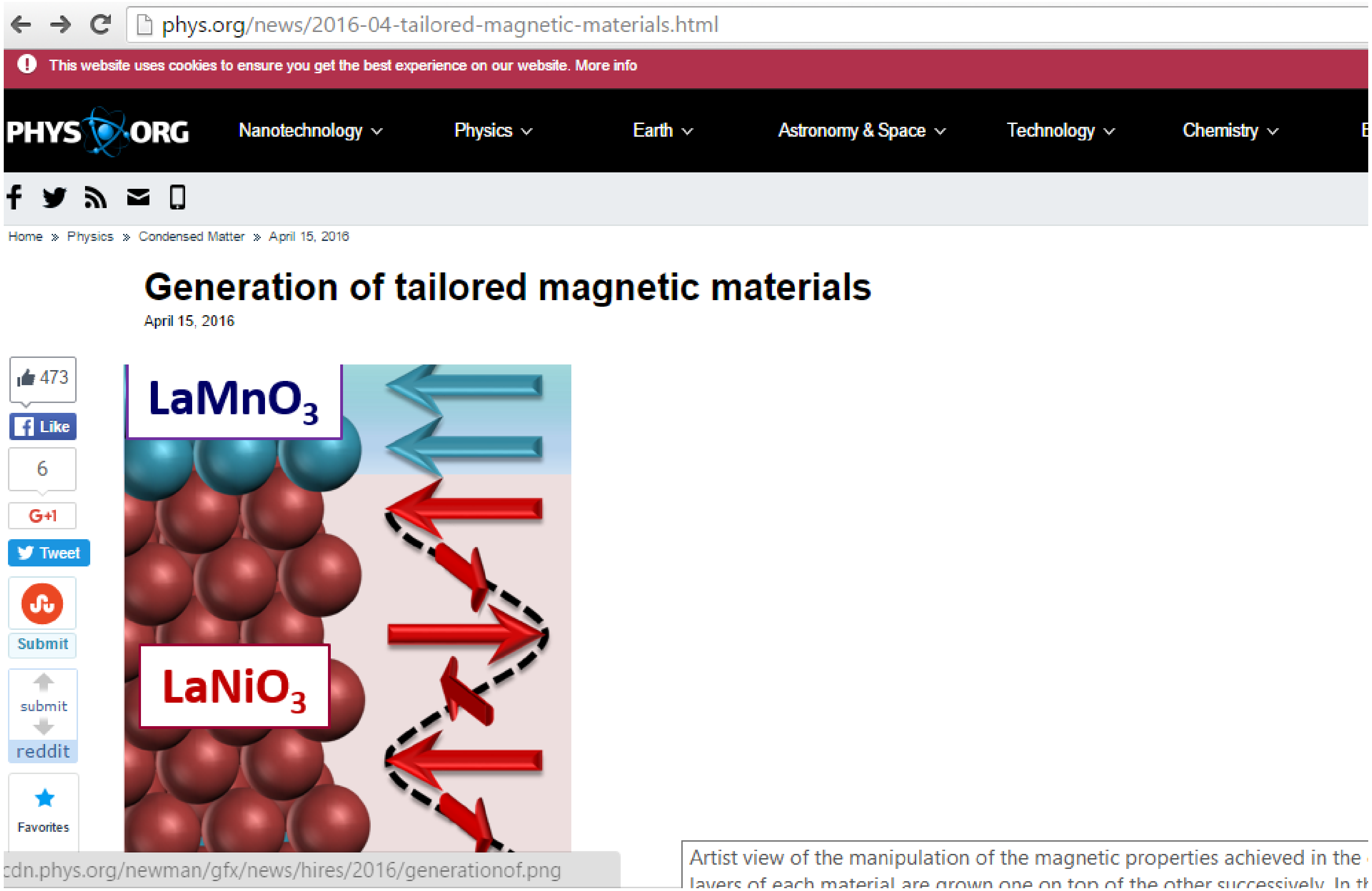
Predicted Radial Displacement (Real T)



Final Thoughts



Standard deviation in measured quantities is due to real material variability (as well as the usual classes of error). In-service measurement may differ from predicted thermal expansion if latter based on mean properties. Thermo-mechanical drift may be variable!



Traditional engineering focus on design and machining (external shape). Could re-designing the (internal) microstructure of materials improve the precision of scientific instruments?

Acknowledgements

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